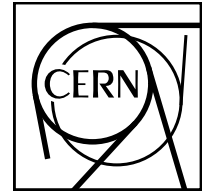
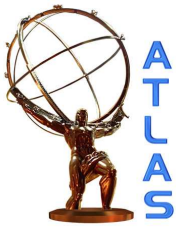


EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)



CERN-PH-EP-2012-139

Submitted to: JHEP

A search for flavour changing neutral currents in top-quark decays in pp collision data collected with the ATLAS detector at $\sqrt{s} = 7$ TeV

The ATLAS Collaboration

Abstract

A search for flavour changing neutral current (FCNC) processes in top-quark decays by the ATLAS Collaboration is presented. Data collected from pp collisions at the LHC at a centre-of-mass energy of $\sqrt{s} = 7$ TeV during 2011, corresponding to an integrated luminosity of 2.1 fb^{-1} , were used. A search was performed for top-quark pair-production events, with one top quark decaying through the $t \rightarrow Zq$ FCNC ($q = u, c$) channel, and the other through the Standard Model dominant mode $t \rightarrow Wb$. Only the decays of the Z boson to charged leptons and leptonic W -boson decays were considered as signal. Consequently, the final-state topology is characterised by the presence of three isolated charged leptons, at least two jets and missing transverse momentum from the undetected neutrino. No evidence for an FCNC signal was found. An upper limit on the $t \rightarrow Zq$ branching ratio of $\text{BR}(t \rightarrow Zq) < 0.73\%$ is set at the 95% confidence level.

A search for flavour changing neutral currents in top-quark decays in pp collision data collected with the ATLAS detector at $\sqrt{s} = 7$ TeV

The ATLAS Collaboration^a

^a*CERN, Geneva*

E-mail: atlas.publications@cern.ch

ABSTRACT: A search for flavour changing neutral current (FCNC) processes in top-quark decays by the ATLAS Collaboration is presented. Data collected from pp collisions at the LHC at a centre-of-mass energy of $\sqrt{s} = 7$ TeV during 2011, corresponding to an integrated luminosity of 2.1 fb^{-1} , were used. A search was performed for top-quark pair-production events, with one top quark decaying through the $t \rightarrow Zq$ FCNC ($q = u, c$) channel, and the other through the Standard Model dominant mode $t \rightarrow Wb$. Only the decays of the Z boson to charged leptons and leptonic W -boson decays were considered as signal. Consequently, the final-state topology is characterised by the presence of three isolated charged leptons, at least two jets and missing transverse momentum from the undetected neutrino. No evidence for an FCNC signal was found. An upper limit on the $t \rightarrow Zq$ branching ratio of $\text{BR}(t \rightarrow Zq) < 0.73\%$ is set at the 95% confidence level.

KEYWORDS: top physics, rare decays, flavour changing neutral currents

Contents

1	Introduction	1
2	Detector and data samples	2
3	Monte Carlo simulation samples	3
3.1	Signal	3
3.2	Background	3
4	Object definition	4
5	Event selection and reconstruction	6
6	Background evaluation	8
7	Systematic uncertainties	10
8	Limit evaluation	12
9	Conclusions	14
10	Acknowledgements	14

1 Introduction

The top quark is the heaviest known elementary particle, with a mass of $m_t = 173.2 \pm 0.9$ GeV [1]. The very large mass may provide a window onto physics beyond the Standard Model (SM). Deviations from SM predictions of the production and decay properties of the top quark provide model-independent tests for physics beyond the SM. According to the SM, the top quark decays nearly 100% of the time to a W boson and a b quark. Flavour changing neutral current (FCNC) decays are highly suppressed in the SM by the GIM mechanism [2] with a branching ratio (BR) of the order of 10^{-14} .

Several SM extensions predict a higher BR for top-quark FCNC decays. Examples of such extensions are the quark-singlet model [3–5], the two-Higgs doublet model with or without flavour-conservation [6–11], the minimal supersymmetric model [12–18], supersymmetry (SUSY) with R -parity violation [19], the topcolour-assisted technicolour model [20] or models with warped extra dimensions [21, 22]. The top-quark FCNC decay BR in these models is typically many orders of magnitude larger than the SM BR, and can be as high as $\sim 2 \times 10^{-4}$ in certain R -parity violating SUSY models.

Existing experimental limits on top-quark FCNC decays come from direct and indirect searches at the Tevatron collider [23, 24], and indirect searches at the LEP [25–30] and

HERA [31, 32] colliders, and at the LHC [33]. The best current direct search limits on the top quark FCNC branching fraction are 3.2% for both $t \rightarrow q\gamma$ [23] and $t \rightarrow Zq$ ($q = u, c$) [24].

This article reports a search for FCNC top-quark decays in $t\bar{t}$ events. Events were searched for in which either the top or antitop quark has decayed into a Z boson and a quark, $t \rightarrow Zq$, while the remaining top or antitop quark decayed through the SM $t \rightarrow Wb$ channel. Only leptonic decays of the Z and W bosons were considered, yielding a final-state topology characterised by the presence of three isolated charged leptons, at least two jets, and transverse momentum imbalance ($E_{\text{T}}^{\text{miss}}$) from the undetected neutrino arising from the W -boson decay. Leptons are either well-identified electron or muon candidates, selected using the full detector or, to increase signal acceptance, isolated tracks. Channels with τ leptons are not explicitly reconstructed, but reconstructed electrons and muons can arise from leptonic τ decays, and an isolated track can arise from hadronic τ decay modes.

2 Detector and data samples

The ATLAS detector [34] at the LHC covers nearly the entire solid angle around the collision point. It consists of an inner tracking detector comprising a silicon pixel detector, a silicon microstrip detector (SCT), and a transition radiation tracker. The inner detector covers the pseudorapidity¹ range $|\eta| < 2.5$ and is surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field, and by lead/liquid-argon (LAr) electromagnetic (EM) sampling calorimeters with high granularity. An iron/scintillator-tile calorimeter provides hadronic energy measurements in the central pseudorapidity range ($|\eta| < 1.7$). The end-cap and forward regions are instrumented with LAr calorimeters for both EM and hadronic energy measurements up to $|\eta| < 4.9$. The calorimeter system is surrounded by a muon spectrometer incorporating three superconducting toroid magnet assemblies (one barrel and two end-caps), with bending power between 2.0 Tm and 7.5 Tm.

A three-level trigger system is used to collect data. The first-level trigger is implemented in hardware and uses a subset of the detector information to reduce the rate to at most 75 kHz. This is followed by two software-based trigger levels that together reduce the event rate to ~ 300 Hz. This analysis uses inclusive single-muon and single-electron triggers with p_{T} thresholds of 18 GeV for muons and 20 GeV or 22 GeV for electrons, depending on the data taking period.

Proton-proton collision data taken at $\sqrt{s} = 7$ TeV by ATLAS between March and August 2011 are used. The data sample corresponds to a total integrated luminosity of 2.1 fb^{-1} with an uncertainty of 3.7% [35, 36]. The mean number of interactions per bunch crossing was 6.2 for the full data sample.

¹In the right-handed ATLAS coordinate system, the pseudorapidity η is defined as $\eta = -\ln[\tan(\theta/2)]$, where the polar angle θ is measured with respect to the LHC beamline. The azimuthal angle ϕ is measured with respect to the x -axis, which points towards the centre of the LHC ring. The y -axis points upwards. Transverse momentum and energy are defined as $p_{\text{T}} = p \sin \theta$ and $E_{\text{T}} = E \sin \theta$, respectively.

3 Monte Carlo simulation samples

Monte Carlo (MC) samples were generated to model both FCNC signal events and certain backgrounds. Alternative MC samples were also generated to evaluate various systematic uncertainties. All generated events are propagated through a detailed **GEANT4** simulation [37, 38] of the ATLAS detector and are reconstructed with the same algorithms as the data. The effect of additional pp interactions in the same bunch crossing as the events of interest was simulated by superimposing additional simulated minimum-bias interactions. The effect from events in neighbouring bunch crossings was also simulated. The simulated events were reweighted such that the average number of extra interactions per crossing (pile-up) matched the data. Data-to-MC scale factors were applied to the MC samples to account for small differences in efficiencies between data and MC simulation.

3.1 Signal

Monte Carlo simulation samples of top-quark pair production, with one of the top quarks decaying through FCNC to Zq while the other decays according to the SM, were generated with **TopReX** [39]. Only decays of the W and Z bosons involving charged leptons were generated ($Z \rightarrow ee, \mu\mu, \tau\tau$ and $W \rightarrow e\nu, \mu\nu, \tau\nu$). The MRST2007 LO* [40] parton distribution function (PDF) set was used with the **TopReX** generator. All signal events were hadronized with **PYTHIA** 6.421 [41]. The masses of the top quark, W boson and Z boson were set to 172.5 GeV, 80.4 GeV and 91.2 GeV, respectively.

To study the effect of the uncertainty due to the top-quark mass, samples with top-quark masses of 170 GeV and 175 GeV were also generated. The uncertainty due to initial- and final-state radiation (ISR/FSR) was evaluated using the **AcerMC** generator [42] interfaced to **PYTHIA**, and by varying the parameters controlling ISR and FSR in a range consistent with those used in the Perugia Hard/Soft tune variations [43].

3.2 Background

Several SM processes have final-state topologies similar to the signal. These include events with three final-state charged leptons (real leptons), as well as events in which at least one jet (including jets with heavy-flavour decays) is misidentified as an isolated charged lepton (‘fake leptons’) and events with four leptons in which one is not reconstructed.

Diboson events (WW , WZ and ZZ) were produced using **ALPGEN** 2.13 [44]. Up to three additional partons from the matrix element were simulated, and the CTEQ6L1 [45] PDF was used. The parton shower and the underlying event were added using **HERWIG** v6.510 [46, 47] and the **JIMMY** [48] underlying event model with the AUET1 tune [49] to the ATLAS data. The **ALPGEN** program with **HERWIG** showering and the **JIMMY** underlying event model was also used to generate Z/γ +jets.

The $t\bar{t}$ and single-top events were generated using the **MC@NLO** generator v3.41 [50–52] with the CTEQ6.6 [53] PDFs [54]. The parton shower and the underlying event were added using **HERWIG** v6.510 and **JIMMY** generators as described above. The $t\bar{t}$ production cross section was normalized to the approximate next-to-next-to-leading-order (NNLO) prediction of 164.6 pb, obtained using the **HATHOR** tool [55]. The cross sections for single-top

production were normalized to the approximate NNLO predictions of 64.6 pb [56], 4.6 pb [57] and 15.7 pb [58] for t -channel, s -channel and associated Wt production, respectively.

Events with $t\bar{t}+W$ and $t\bar{t}+Z$ production, including those with extra jets in the final state, were generated using MADGRAPH 4.4.62 [59]. Parton showering was added using PYTHIA.

All decay modes of the W and Z bosons to charged leptons were considered in the generation and simulation of the background samples used.

Backgrounds that include fake leptons were evaluated using a data-driven approach described below.

4 Object definition

The selection of leptons, jets, and $E_{\text{T}}^{\text{miss}}$ was close to that used for the ATLAS measurement of the $t\bar{t}$ production cross section in the dilepton channel [60]. Leptons were selected either using the full ATLAS detector, including the inner detector, calorimeter and muon spectrometer (‘identified leptons’ or ‘ID leptons’), or using only a high quality inner detector track (‘track leptons’ or ‘TLs’). The inclusion of TLs increased the acceptance for $W \rightarrow \tau\nu$ decays, and for electrons and muons that fail the ID lepton selection criteria. TLs were required to be distinct from ID leptons, and at most one TL per event was allowed. Signal candidates selected with three identified leptons are referred to as ‘3ID’ events, and those selected with two identified leptons and a TL are referred to as ‘2ID+TL’ events. The 2ID+TL events increased the signal acceptance by 22% compared to a 3ID selection alone.

ID electron candidates were reconstructed from energy deposits (clusters) in the EM calorimeter, which were then associated to reconstructed tracks of charged particles in the inner detector. Stringent quality requirements on the conditions of the EM calorimeter at the time of data taking were applied to ensure a well-measured reconstructed energy. A ‘tight’ selection [61] using calorimeter, tracking and combined variables, was employed to provide good separation between the signal electrons and background. Electron candidates were additionally required to have $|\eta_{\text{cl}}| < 2.47$, excluding electrons in the transition region between the barrel and endcap calorimeters defined by $1.37 < |\eta_{\text{cl}}| < 1.52$. The variable η_{cl} is the pseudorapidity of the energy cluster associated with the candidate.

ID muon candidate reconstruction began by searching for track segments in layers of the muon chambers. These segments were combined starting from the outermost layer, fitted to account for material effects, and matched with tracks found in the inner detector. The candidates were refitted using the complete track information from both detector systems, and were required to satisfy $|\eta| < 2.5$.

Candidates for TL were defined by an inner-detector track and a series of quality cuts optimized for high efficiency and a low rate of misidentification. The track was required to have at least six pixel and/or SCT hits and at least one hit in the innermost pixel layer. The transverse distance of closest approach of the track to the beamline, d_0 , was required to satisfy $|d_0| < 0.2$ mm and the uncertainty on the momentum measurement was required to be less than 20%.

All leptons were required to be isolated and have high transverse momentum, p_T , consistent with originating from W - or Z -boson decay. Because of the requirement of three leptons in this analysis, lepton thresholds were reduced from those used in Ref. [60]. In 3ID events, the leading lepton was required to have $p_T > 25$ GeV, and the two sub-leading leptons were required to have $p_T > 20$ GeV. In 2ID+TL events, the TL was required to have $p_T > 25$ GeV, and the two ID leptons in the event were required to have $p_T > 20$ GeV. At least one ID lepton was required to have fired the trigger. To ensure good trigger efficiency with the higher electron trigger thresholds, reconstructed electrons that were associated with trigger objects were required to have $p_T > 25$ GeV.

Lepton isolation requirements reduce backgrounds from misidentified jets and suppress the selection of leptons from heavy-flavour decays. For ID electron candidates, E_T deposited in the calorimeter cells but not associated to the electron was summed in a cone with radius² $\Delta R = 0.2$ around the electron and required to be less than 3.5 GeV. For ID muon candidates, the isolation requirement was based on both calorimeter and track information. The track isolation requirement was based on the sum of the track transverse momenta, for tracks with $p_T > 1$ GeV in a cone with radius $\Delta R = 0.3$ centred on the muon candidate, while the calorimeter isolation requirement was based on the transverse energy in the same cone. Both the track and calorimeter sums, excluding the muon candidate, were required to be less than 4 GeV. Additionally, ID muon candidates were required to have a distance $\Delta R > 0.4$ from any jet with $p_T > 20$ GeV, further suppressing muon candidates from heavy-flavour decays. For TLs, the track was required to be isolated from other nearby tracks following the track isolation definition above, in this case using tracks with $p_T > 0.5$ GeV. The summed momentum cut was set to 2 GeV. ID muon candidates arising from cosmic rays were rejected by removing candidate pairs that were back-to-back in the $r - \phi$ plane and with transverse impact parameters relative to the beam axis $|d_0| > 0.5$ mm.

Jets were reconstructed with the anti- k_t algorithm [62] with a radius parameter $R = 0.4$, starting from energy clusters in the calorimeter reconstructed using the scale established for electromagnetic objects. These jets were then calibrated to the hadronic energy scale using p_T - and η -dependent correction factors [63]. Jets were removed if they are within $\Delta R < 0.2$ of a well-identified electron candidate, or within $\Delta R < 0.4$ of a TL. The jets used in the analysis were required to have $p_T > 25$ GeV and $|\eta| < 2.5$.

To suppress backgrounds in which TLs are reconstructed from fake leptons, a jet consistent with originating from a b quark was required in events with a TL. Jets were identified as b -quark candidates (b -tagged) by an algorithm that forms a likelihood ratio of b - to light-quark jet hypotheses using several kinematic variables [64]. The cut on the combined likelihood ratio was chosen such that a b -tagging efficiency of $\approx 80\%$ per b -jet in $t\bar{t}$ candidate events was achieved.

The E_T^{miss} vector was formed from the negative vector sum of the transverse momenta of the reconstructed objects (electrons, muons, jets) [65]. The contribution from cells associated with electron candidates was replaced by the calibrated transverse energy of

² $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$

the candidate. The contribution from all ID muon candidates and calorimeter clusters (including those not belonging to a reconstructed object) was also included. TL candidates that arise from muons and leave little energy in the calorimeter are not properly included in the E_T^{miss} . In such events the E_T^{miss} often points close to the TL direction. In these events the E_T^{miss} was corrected with the p_T of the TL if the TL and an oppositely-charged ID muon were consistent with coming from a Z -boson decay, and if the $\Delta\phi$ between the E_T^{miss} and the TL direction was less than 0.15 and there is no ID lepton within $\Delta R=0.05$ of the TL (in which case the correction was already included by the E_T^{miss} algorithm). After all corrections, $E_T^{\text{miss}} > 20$ GeV was required.

5 Event selection and reconstruction

The analysis required collision data selected by an inclusive single-electron or single-muon trigger. To ensure that the event was triggered by the lepton candidates used in the analysis, one of the identified leptons and the triggered lepton were required to match within $\Delta R < 0.15$.

Events were required to have a primary interaction vertex with at least five tracks with $p_T > 400$ MeV. The event was discarded if it had any jet with $p_T > 20$ GeV that failed quality cuts designed to reject jets arising from calorimeter noise or activity inconsistent with the bunch-crossing time [63]. If an electron candidate and a muon candidate shared a track, the event was also discarded.

During part of the data-taking period, corresponding to an integrated luminosity of 0.9 fb^{-1} , an electronics failure in a small $\eta - \phi$ region of the LAr EM calorimeter created a dead region. For this subset of the data, events in data and MC simulation containing either an identified electron or a jet with $p_T > 20$ GeV, satisfying $-0.1 < \eta < 1.5$ and $-0.9 < \phi < -0.5$ were rejected.

Events were selected as either 3ID or 2ID+TL candidates, each with thresholds described in Section 4. In both cases, all three lepton candidates were required to come from the same primary interaction vertex. In addition, signal candidates were required to have at least two jets and $E_T^{\text{miss}} > 20$ GeV. In events selected with a TL, at least one jet was required to be b -tagged. Figure 1 shows the E_T^{miss} distribution for the 3ID and 2ID+TL events prior to the final selection requirements. For the 3ID case these are events with three identified leptons with at least one opposite-sign, same-flavour pair with an invariant mass consistent with a Z -boson, but no jets or E_T^{miss} requirement. In the 2ID+TL case, these are events with an opposite-sign pair and both the jet and E_T^{miss} requirements, but no Z -boson selection.

Selected events were required to be kinematically consistent with $t\bar{t} \rightarrow WbZq$ through a χ^2 minimized with respect to jet and lepton assignments and the longitudinal momentum of the neutrino, p_z^ν . The χ^2 was defined as follows

$$\chi^2 = \frac{\left(m_{j_a \ell_a \ell_b}^{\text{reco}} - m_t\right)^2}{\sigma_t^2} + \frac{\left(m_{j_b \ell_c \nu}^{\text{reco}} - m_t\right)^2}{\sigma_t^2} + \frac{\left(m_{\ell_c \nu}^{\text{reco}} - m_W\right)^2}{\sigma_W^2} + \frac{\left(m_{\ell_a \ell_b}^{\text{reco}} - m_Z\right)^2}{\sigma_Z^2}, \quad (5.1)$$

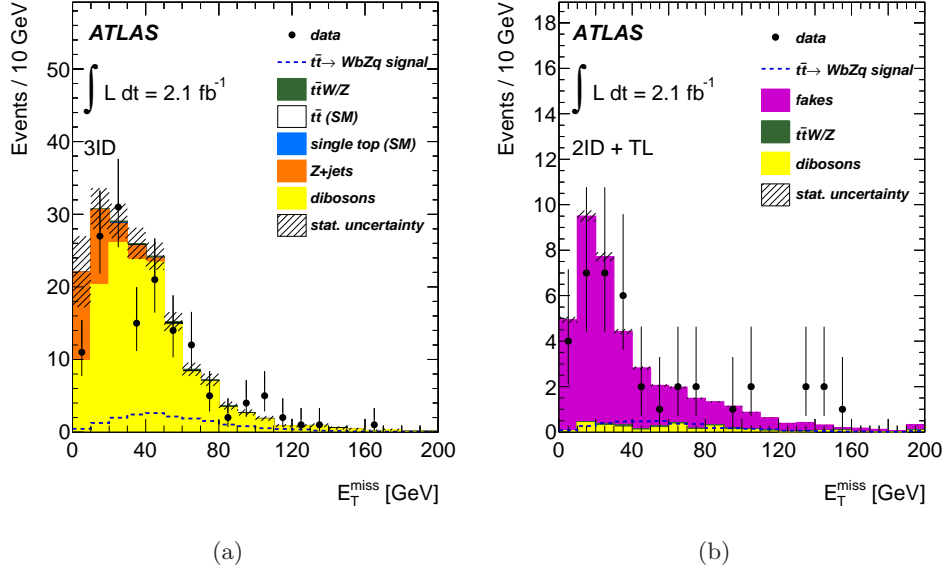


Figure 1. E_T^{miss} distributions before the final selection for the (a) 3ID and (b) 2ID+TL analysis. For the 3ID case these are events with three identified leptons with at least one opposite-sign, same-flavour pair with an invariant mass consistent with a Z -boson, but no jets or E_T^{miss} requirement. In the 2ID+TL case, these are events with an opposite-sign pair and both the jet and E_T^{miss} requirements, but no Z -boson selection. The uncertainties shown are statistical only.

where $j_{a,b}$ are the two highest- p_T jets in the event and $\ell_{a,b,c}$ are the three lepton candidates. The constraints were defined as follows: $m_t = 172.5$ GeV, $m_W = 80.4$ GeV, $m_Z = 91.2$ GeV. The widths were derived from MC studies and set to $\sigma_t = 14$ GeV, $\sigma_W = 10$ GeV and $\sigma_Z = 3$ GeV. The transverse momentum of the neutrino was set equal to E_T^{miss} , and all jet and lepton assignments were tried, subject to the requirement that the Z candidate be built from same-flavour opposite-charge leptons. Any opposite-charge ID lepton–TL pair can be used as leptons from the Z -boson decay, because the TL is assumed to be the same flavour as the ID lepton. No b -jet identification was used in the reconstruction of the event kinematics. For each assignment, the value of p_z^ν was defined to be that which gave the minimum χ^2 . From all combinations, the one with the smallest χ^2 was chosen along with the corresponding p_z^ν value. Events were rejected unless the reconstructed top-quark masses were within 40 GeV of m_t , the reconstructed W -boson mass was within 30 GeV of m_W , and the reconstructed Z -boson mass was within 15 GeV of m_Z . The effect of these mass cuts on the fake-TL background expectation was derived from simulation by measuring the fraction of simulated 2ID+TL background events with fake TLs that pass the χ^2 mass cuts. This fraction is $(31 \pm 10)\%$. Of the events that pass all other event selection requirements, 38% (29%) of the 3ID (2ID+TL) events pass the χ^2 mass cuts. The efficiency for FCNC MC events to pass the χ^2 -based mass cuts is $(79 \pm 2)\%$ ($(66 \pm 2)\%$), while for background MC events it is only $(47 \pm 7)\%$ ($(33 \pm 10)\%$) for 3ID (2ID+TL) events.

The signal efficiency for $t\bar{t} \rightarrow WbZq$, after all selection requirements, was determined

using the TopReX sample described in Section 3 and is shown in Table 1.

6 Background evaluation

Backgrounds to this search can be divided into two categories: those with three real leptons and those with at least one fake lepton. Backgrounds with three real leptons arise from diboson (WZ and ZZ) production with additional jets, and were evaluated using the MC samples described in Section 3.2. In the case of WZ production, the required E_T^{miss} comes from the neutrino from the leptonic W -boson decay. Events from ZZ decays can enter the signal region in several ways; the dominant modes are four-lepton decays with one lepton not reconstructed, giving apparent E_T^{miss} , and $\tau^+\tau^-$ decays with one τ decaying to e or μ and two neutrinos.

The background to 3ID candidate events, in which exactly one of the leptons is a fake lepton, was evaluated using a combination of data and MC samples. The dominant contribution in this category comes from Z +jets events, with a leptonic Z decay, in which one of the jets was misidentified as a third lepton. To evaluate this background a data-driven (DD) method was used. This method uses a control region (CR) in the $(E_T^{\text{miss}}, m_{\ell\ell})$ plane by selecting events with exactly two opposite-charge electrons or muons (no third ID lepton is allowed) and $|91.2 \text{ GeV} - m_{\ell\ell}^{\text{reco}}| < 15 \text{ GeV}$ in six different E_T^{miss} bins from 0 GeV to $\geq 50 \text{ GeV}$. The Z +jets estimate in each E_T^{miss} bin is then given by:

$$[N_{Z+\text{jets}}^{\text{Data}}]_{\text{SR}} = \left[\frac{N^{\text{Data}} - N_{\text{Other backgrounds}}^{\text{MC}}}{N_{Z+\text{jets}}^{\text{MC}}} \right]_{\text{CR}} \cdot [N_{Z+\text{jets}}^{\text{MC}}]_{\text{SR}}. \quad (6.1)$$

For each E_T^{miss} bin considered, the corresponding background-subtracted data/simulation ratio in the CR was applied to the simulated Z +jets background in the signal regions (SR), in order to evaluate the expected number of Z +jets events in the data. To enhance the statistical power of the MC sample, the lepton selection was loosened compared to the SR lepton selection. A multiplicative factor of 0.063 ± 0.013 , corresponding to the MC probability for events with loose leptons to pass the SR lepton criteria, was applied to the final result. The remaining backgrounds with one fake lepton (dileptonic $t\bar{t}$, Wt -channel single-top and WW production) were evaluated using Monte Carlo simulation samples, described in Section 3, and the loose lepton selection and multiplicative factor above. Different DD methods and cross-checks for the one-fake-lepton background were performed. These include the matrix method [66], relaxation of E_T^{miss} or lepton quality requirements, and MC simulation with fake-rate factors measured from data. These alternative methods, although statistically limited, agree with the reference DD+MC method used.

A DD method was developed to evaluate the contribution to 3ID events from multi-jet, W +jets, single-top and $t\bar{t}$ single-lepton decay events, in which two or three jets were reconstructed as leptons (2+3 fake leptons). Due to the requirement that two leptons should have the same flavour and opposite charges, the yield from these backgrounds can be extrapolated from the number of observed data events with three leptons of any flavour (e or μ), but with the same charge. Taking into account the possible charge and flavour

combinations, there are 36 combinations of three leptons, in which two have the same flavour and opposite charges, and 16 combinations of three leptons with the same charge. The extrapolation factor is thus $f = 36/16 = 2.25$. No data event passed the selection after requiring three leptons with the same charge. The uncertainties in the DD backgrounds were determined using the Feldman-Cousins upper interval for a 68% C.L. [67] with no observed events (with the uncertainties multiplied by 2.25 for the 2+3 fake leptons sample). Since no events were selected with three leptons of the same charge, a multiplicative factor of 0.071 ± 0.018 , to account for the final requirements of at least two jets with $p_T > 25$ GeV and $E_T^{\text{miss}} > 20$ GeV was evaluated using MC samples and applied to the uncertainty estimate.

In 2ID+TL events the dominant background contribution comes from events with a fake TL. The background contribution from such events was evaluated with the same technique used in Ref. [60]: the probability of a jet being reconstructed as a track lepton was determined from a γ +jets data sample selected with photon triggers, and parameterized in a ‘fake matrix’ as a function of jet p_T and the number of primary vertices in the event, N_{vtx} . The number of primary vertices was needed in the parameterization because the fake probability is sensitive to pile-up. The fake matrix was applied to a ‘parent sample’ selected with all of the signal region requirements with the exception of the three leptons. Instead, two ID leptons were required. Fake probabilities from the matrix were summed for each jet in the parent sample, according to its p_T and N_{vtx} for each event. The resulting sum is the fake TL background contribution. Because of the b -tag requirement in events with a TL, a b -tagged jet was allowed to contribute to the sum only if there was another b -tagged jet in the event. This accounts for the fact that if a jet produced a fake TL, the remaining jet would be removed by the lepton–jet overlap removal described in Section 4. For the same reason, events with three or more jets were used to predict the number of fake TLs in events with two or more jets. The signal region required a Z -boson candidate, i.e. an opposite-charge, same-flavour lepton pair. Therefore the parent sample with two ID leptons provides three different cases:

1. Opposite-charge ID leptons
2. Two positively-charged ID leptons
3. Two negatively-charged ID leptons

In case 1, the fake TL was allowed to have either charge. In case 2 the fake TL was required to be negatively charged, and in case 3 positively charged. Three different fake matrices were constructed to account for these three cases, one in which both charges are used, and one with only negatively or positively charged TLs. When a TL and an oppositely-charged ID lepton had an invariant mass consistent with arising from a Z boson, the same-flavour requirement was automatically satisfied because the TL is taken to have the same flavour as the ID lepton. The parent sample with two ID leptons contains all sources of backgrounds that can enter the signal region with a fake TL, including those with one or two fake ID leptons. Thus the procedure predicts the full background contribution

with a fake TL. A small contribution (2% of the total), evaluated from the MC simulation, was included to account for events with a ‘real’ TL and a fake ID lepton.

A summary of expected backgrounds and selected data events in both the 3ID lepton and 2ID+TL samples is shown in Table 1.

Table 1. Expected number of background events, number of selected data events and signal efficiency (normalized to all decays of the W and Z bosons), after the final event selection. The $t\bar{t}$ backgrounds correspond to SM decays of the top quarks. The third entry in the 2ID+TL column corresponds to the fake TL background and includes all sources of events in the left-hand column except ZZ , WZ , $t\bar{t}W$ and $t\bar{t}Z$.

	3ID	2ID+TL
ZZ and WZ	9.5 \pm 4.4	1.0 \pm $\begin{smallmatrix} 0.5 \\ 0.6 \end{smallmatrix}$
$t\bar{t}W$ and $t\bar{t}Z$	0.51 \pm 0.14	0.25 \pm 0.05
$t\bar{t}$, WW	0.07 \pm 0.02	
Z +jets	1.7 \pm 0.7	7.6 \pm 2.2
Single top	0.01 \pm 0.01	
2+3 fake leptons	0.0 \pm $\begin{smallmatrix} 0.2 \\ 0.0 \end{smallmatrix}$	
Expected background	11.8 \pm 4.4	8.9 \pm 2.3
Data	8	8
Signal efficiency	(0.205 \pm 0.024)%	(0.045 \pm 0.007)%

Figure 2 shows the reconstructed candidate Z -boson and top-quark masses, m_{ll} and m_{llq} respectively, for the FCNC decay hypothesis in the selected candidate events, for both the 3ID and 2ID+TL data, compared with the expectations from SM backgrounds and the FCNC signal.

7 Systematic uncertainties

A number of systematic uncertainties can influence the expected number of signal and/or background events. The effect of each source of systematic uncertainty was studied by independently varying the corresponding central value by the estimated uncertainty. For each variation, the total number of expected background events and the signal efficiencies were compared with the reference values.

The measurement of the integrated luminosity has a total uncertainty of 3.7% [35, 36]. This uncertainty was considered in the analyses by changing the normalizations of the backgrounds evaluated from MC simulation. Uncertainties associated with the energy scale of light-quark jets and b -jets were studied as a function of the jet transverse momentum and pseudorapidity. These uncertainties, including the effects of pile-up, are in the range 6–10% [63]. The effects of the jet reconstruction efficiency uncertainty were studied by randomly removing about 2% of jets from the events. The effect of potential jet resolution mis-modelling in the MC simulation was evaluated by additional smearing of the reconstructed jet energies within the uncertainties. In each case, the difference with respect to

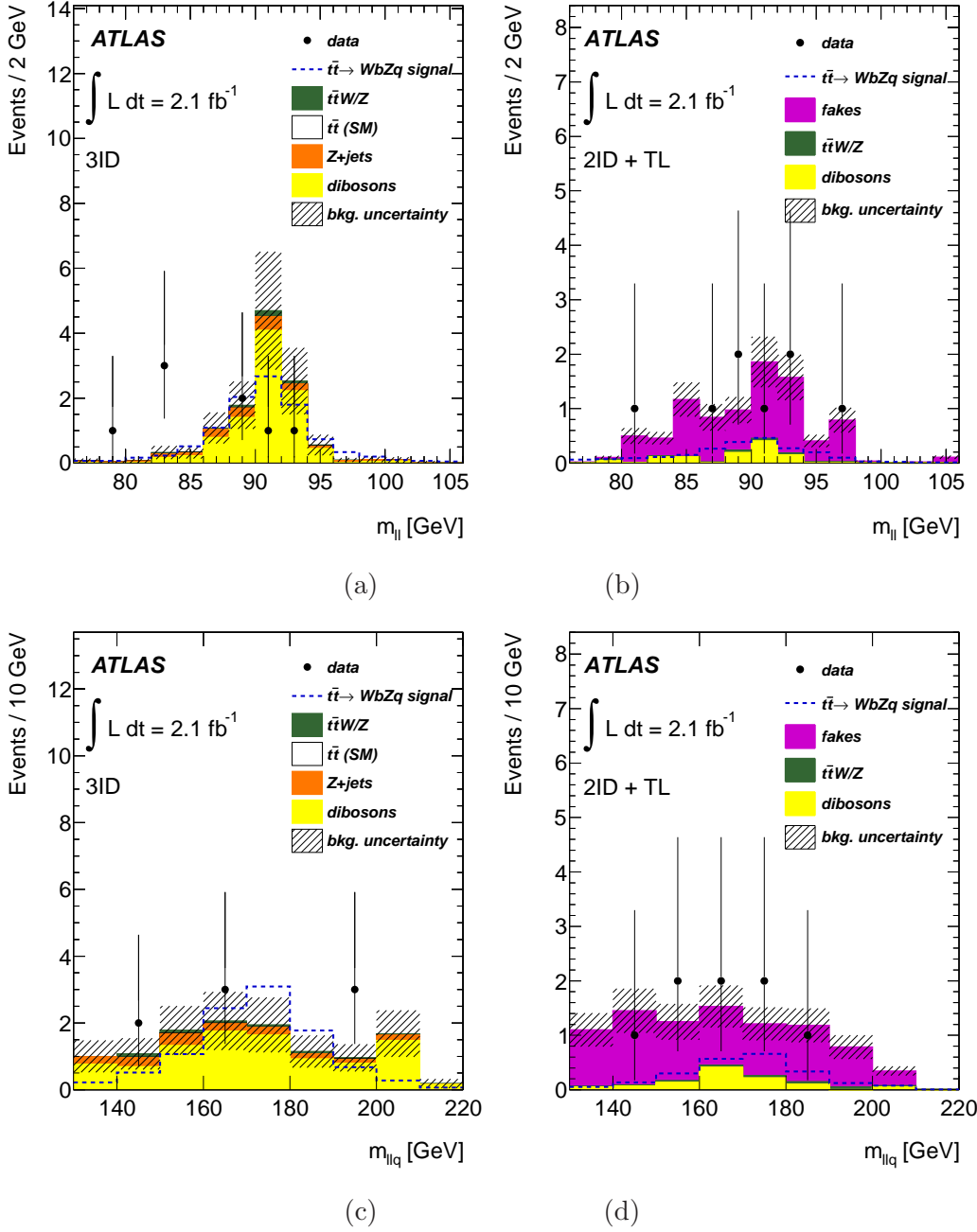


Figure 2. Expected and observed Z-boson and top-quark mass distributions for the FCNC decay hypothesis in the 3ID ((a) & (c)) and 2ID+TL ((b) & (d)) candidate events after all selection requirements. The $t\bar{t} \rightarrow WbZq$ distributions are normalized to the observed limit in each channel.

the nominal simulation was considered as the systematic uncertainty. The uncertainties due to MC modelling of the lepton trigger, reconstruction and selection efficiencies, and b -tagging efficiency, were taken into account by re-computing the predicted event yields and signal acceptance using the corresponding systematic shift. The momentum of the lepton

in simulation was rescaled and smeared to correct for scale and resolution disagreements between simulated and observed data. The systematic uncertainty associated with the modelling of the momentum scale and resolution was evaluated by shifting the momentum scale and changing the smearing factors. Changes applied to electrons, muons and jets were propagated to E_T^{miss} . Uncertainties related to E_T^{miss} were also studied: the effect of the energy in the calorimeter not associated with the above objects, and of low momentum ($7 \text{ GeV} < p_T < 20 \text{ GeV}$) jets, was studied, as well as the uncertainty due to modelling of pile-up. The effect of a hardware failure in the electromagnetic calorimeter was also considered as a systematic uncertainty (LAr readout problem) and evaluated by varying the jet thresholds used for removing events with jets directed at the dead region. The effects of ISR/FSR and top-quark mass uncertainties were evaluated using the MC samples described in Section 3. The effect of uncertainties in the PDF used for signal generation was evaluated by comparing the signal acceptance using MSTW2008LO with that from MRST2007 LO* PDFs. The systematic uncertainties related to the ZZ and WZ simulation modelling were estimated using the Berends-Giele scaling [68, 69] with an uncertainty of 24% per jet, added in quadrature. An uncertainty of 4% was included for the 0-jet bin. The ZZ and WZ cross sections were varied by their theoretical uncertainty of 5% [70]. The uncertainties on the Z +jets normalizations were derived using a data-driven method. In the 2ID+TL channel, where b -tagging was used, a systematic uncertainty associated with the heavy-flavour content of WZ +jets and ZZ +jets is included. This was evaluated by comparing ALPGEN and MC@NLO, and is small because the dominant source of b -tags in these events comes from mis-tags of light-quark jets, with a secondary component from charm jets.

The dominant source of systematic uncertainty for the 3ID channel is the ZZ and WZ simulation modelling. The other sources have effects at most of the same magnitude as the statistical uncertainty. The dominant uncertainty in the 2ID+TL channel is the systematic uncertainty on the fake-TL prediction, because 90% of the expected background arises from this source. This was determined to be 20% by comparing predicted and observed events with TLs in control regions dominated by fake TLs [60].

The resulting uncertainties for the backgrounds and signal acceptance are shown in Table 2. Because almost 90% of the 2ID+TL background evaluation is data-driven, the 2ID+TL analysis has a smaller relative background systematic uncertainties in most categories, compared to the 3ID analysis.

8 Limit evaluation

Good agreement between data and expected background yields was observed, as shown in Table 1. No evidence for the $t \rightarrow Zq$ decay mode was found and 95% C.L. upper limits on the number of signal events were derived using the modified frequentist (CL_s) likelihood method [71, 72]. The statistical fluctuations of the pseudo-experiments were performed using Poisson distributions. All statistical and systematic uncertainties of the expected backgrounds and signal efficiencies were taken into account, as described in Section 7 and were implemented assuming Gaussian distributions [71]. The systematic uncertainties of

Table 2. Relative changes in the expected number of background events and signal yield for different sources of systematic uncertainties. The contributions from the ZZ and WZ event generator apply only to the simulated background samples.

Source	3ID		2ID+TL	
	Background	Signal	Background	Signal
Luminosity	4%	4%	<1%	4%
Electron trigger	4%	1%	<1%	<1%
Electron reconstruction modelling	10%	3%	<1%	2%
Muon trigger	3%	1%	<1%	<1%
Muon reconstruction modelling	7%	1%	<1%	1%
TL reconstruction modelling	—	—	2%	1%
Jet energy scale	11%	1%	1%	1%
Jet reconstruction efficiency	5%	2%	<1%	<1%
Jet energy resolution	1%	3%	1%	4%
E_T^{miss} modelling	4%	1%	<1%	<1%
LAr readout problem	3%	1%	<1%	1%
Pile-up	4%	<1%	<1%	<1%
b -tagging	—	—	1%	6%
Top quark mass	<1%	2%	—	3%
$\sigma_{t\bar{t}}$	<1%	8%	—	8%
ISR/FSR	<1%	3%	—	6%
PDFs	—	3%	—	3%
ZZ and WZ shape	33%	—	5%	—
ZZ and WZ cross section	4%	—	<1%	—
ZZ and WZ heavy-flavour content	—	—	<1%	—
Fake leptons	1%	—	17%	—
Total	38%	12%	18%	15%

the ZZ , WZ and signal acceptance were considered to be fully correlated between the 3ID and 2ID+TL channels, while all other sources of uncertainties (statistical or systematic) were considered uncorrelated. The limits on the number of signal events were converted into upper limits on the corresponding BRs using the approximate NNLO calculation, and its uncertainty, for the $t\bar{t}$ cross section ($\sigma_{t\bar{t}} = 165_{-16}^{+11}$ pb) [73], and constraining $\text{BR}(t \rightarrow Wb) = 1 - \text{BR}(t \rightarrow Zq)$. The observed 95% C.L. upper limit on the FCNC $t \rightarrow Zq$ BR is 0.82% (3.2%) taking the 3ID (2ID+TL) events and background evaluation alone, and 0.73% when the 3ID and 2ID+TL results are combined. Table 3 shows the observed and expected limits in the absence of signal for the 3ID and 2ID+TL channels, as well as for the combination. Also shown are the $\pm 1\sigma$ expected limits.

Table 3. The expected and observed 95% C.L. upper limits on the FCNC top quark decay $t \rightarrow Zq$ BR. The $\pm 1\sigma$ expected limits include both statistical and systematic uncertainties.

channel	observed	(-1σ)	expected	$(+1\sigma)$
3ID	0.81%	0.63%	0.95%	1.4%
2ID+TL	3.2%	2.15%	3.31%	4.9%
Combination	0.73%	0.61%	0.93%	1.4%

9 Conclusions

A search for FCNC decays of top quarks produced in pairs was performed using data collected by the ATLAS experiment at a centre-of-mass energy of $\sqrt{s} = 7$ TeV and corresponding to an integrated luminosity of 2.1 fb^{-1} . The search for the $t \rightarrow qZ$ decay mode was performed by studying top-quark pair production with one top quark decaying according to the Standard Model and the other according to the FCNC ($t\bar{t} \rightarrow bWqZ$). No evidence for such a signal was found. An observed limit at 95% C.L. on the $t \rightarrow qZ$ FCNC top-quark decay branching fraction was set at $\text{BR}(t \rightarrow qZ) < 0.73\%$, assuming $\text{BR}(t \rightarrow bW) + \text{BR}(t \rightarrow qZ) = 1$. The observed limit is compatible with the expected sensitivity, assuming that the data are described correctly by the Standard Model, of $\text{BR}(t \rightarrow qZ) < 0.93\%$.

10 Acknowledgements

We thank CERN for the very successful operation of the LHC, as well as the support staff from our institutions without whom ATLAS could not be operated efficiently.

We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; CONICYT, Chile; CAS, MOST and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DNRF, DNSRC and Lundbeck Foundation, Denmark; EPLANET and ERC, European Union; IN2P3-CNRS, CEA-DSM/IRFU, France; GNAS, Georgia; BMBF, DFG, HGF, MPG and AvH Foundation, Germany; GSRT, Greece; ISF, MINERVA, GIF, DIP and Benoziyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; FOM and NWO, Netherlands; RCN, Norway; MNiSW, Poland; GRICES and FCT, Portugal; MERYS (MECTS), Romania; MES of Russia and ROSATOM, Russian Federation; JINR; MSTD, Serbia; MSSR, Slovakia; ARRS and MVZT, Slovenia; DST/NRF, South Africa; MICINN, Spain; SRC and Wallenberg Foundation, Sweden; SER, SNSF and Cantons of Bern and Geneva, Switzerland; NSC, Taiwan; TAEK, Turkey; STFC, the Royal Society and Leverhulme Trust, United Kingdom; DOE and NSF, United States of America.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN and the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF

(Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA) and in the Tier-2 facilities worldwide.

References

- [1] **CDF and D0** Collaboration, *Combination of CDF and D0 results on the mass of the top quark using up to 5.8 fb^{-1} of data*, [arXiv:1107.5255](#).
- [2] S. L. Glashow, J. Iliopoulos, and L. Maiani, *Weak Interactions with Lepton-Hadron Symmetry*, Phys. Rev. **D2** (1970) 1285.
- [3] J. A. Aguilar-Saavedra and B. M. Nobre, *Rare top decays $t \rightarrow c\gamma, t \rightarrow cg$ and CKM unitarity*, Phys. Lett. **B553** (2003) 251, [[hep-ph/0210360](#)].
- [4] F. del Aguila, J. A. Aguilar-Saavedra, and R. Miquel, *Constraints on top couplings in models with exotic quarks*, Phys. Rev. Lett. **82** (1999) 1628, [[hep-ph/9808400](#)].
- [5] J. A. Aguilar-Saavedra, *Effects of mixing with quark singlets*, Phys. Rev. **D67** (2003) 035003, [[hep-ph/0210112](#)]. Erratum-ibid. **D69** (2004) 099901.
- [6] T. P. Cheng and M. Sher, *Mass Matrix Ansatz and Flavor Nonconservation in Models with Multiple Higgs Doublets*, Phys. Rev. **D35** (1987) 3484.
- [7] B. Grzadkowski, J. F. Gunion, and P. Krawczyk, *Neutral current flavor changing decays for the Z boson and the top quark in two Higgs doublet models*, Phys. Lett. **B268** (1991) 106.
- [8] M. E. Luke and M. J. Savage, *Flavor changing neutral currents in the Higgs sector and rare top decays*, Phys. Lett. **B307** (1993) 387, [[hep-ph/9303249](#)].
- [9] D. Atwood, L. Reina, and A. Soni, *Probing flavor changing top - charm - scalar interactions in e^+e^- collisions*, Phys. Rev. **D53** (1996) 1199, [[hep-ph/9506243](#)].
- [10] D. Atwood, L. Reina, and A. Soni, *Phenomenology of two Higgs doublet models with flavor changing neutral currents*, Phys. Rev. **D55** (1997) 3156, [[hep-ph/9609279](#)].
- [11] S. Bejar, J. Guasch, and J. Sola, *Loop induced flavor changing neutral decays of the top quark in a general two-Higgs-doublet model*, Nucl. Phys. **B600** (2001) 21, [[hep-ph/0011091](#)].
- [12] C. S. Li, R. J. Oakes, and J. M. Yang, *Rare decay of the top quark in the minimal supersymmetric model*, Phys. Rev. **D49** (1994) 293. Erratum-ibid. **D56**:3156, 1997.
- [13] G. M. de Divitiis, R. Petronzio, and L. Silvestrini, *Flavour changing top decays in supersymmetric extensions of the standard model*, Nucl. Phys. **B504** (1997) 45, [[hep-ph/9704244](#)].
- [14] J. L. Lopez, D. V. Nanopoulos, and R. Rangarajan, *New supersymmetric contributions to $t \rightarrow cV$* , Phys. Rev. **D56** (1997) 3100, [[hep-ph/9702350](#)].
- [15] J. Guasch and J. Sola, *FCNC top quark decays: A door to SUSY physics in high luminosity colliders?*, Nucl. Phys. **B562** (1999) 3, [[hep-ph/9906268](#)].
- [16] D. Delepine and S. Khalil, *Top flavour violating decays in general supersymmetric models*, Phys. Lett. **B599** (2004) 62, [[hep-ph/0406264](#)].
- [17] J. J. Liu, C. S. Li, L. L. Yang, and L. G. Jin, *$t \rightarrow cV$ via SUSY FCNC couplings in the unconstrained MSSM*, Phys. Lett. **B599** (2004) 92, [[hep-ph/0406155](#)].
- [18] J. J. Cao et al., *SUSY-induced FCNC top-quark processes at the Large Hadron Collider*, Phys. Rev. **D75** (2007) 075021, [[hep-ph/0702264](#)].

- [19] J. M. Yang, B.-L. Young, and X. Zhang, *Flavor-changing top quark decays in R-parity violating SUSY*, Phys. Rev. **D58** (1998) 055001, [[hep-ph/9705341](#)].
- [20] G. Lu, F. Yin, X. Wang, and L. Wan, *The rare top quark decays $t \rightarrow cV$ in the topcolor-assisted technicolor model*, Phys. Rev. **D68** (2003) 015002, [[hep-ph/0303122](#)].
- [21] G. P. K. Agashe and A. Soni, *Flavor structure of warped extra dimension models*, Phys. Rev. **D71** (2005) 016002, [[hep-ph/0408134](#)].
- [22] G. P. K. Agashe and A. Soni, *Collider Signals of Top Quark Flavor Violation from a Warped Extra Dimension*, Phys. Rev. D **75** (2007) 015002, [[hep-ph/0606293](#)].
- [23] **CDF** Collaboration, F. Abe et al., *Search for flavor-changing neutral current decays of the top quark in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV*, Phys. Rev. Lett. **80** (1998) 2525.
- [24] **D0** Collaboration, V. M. Abazov et al., *Search for flavor changing neutral currents in decays of top quarks*, Phys. Lett. B **701** (2011) 313.
- [25] **ALEPH** Collaboration, A. Heister et al., *Search for single top production in e^+e^- collisions at \sqrt{s} up to 209 GeV*, Phys. Lett. **B543** (2002) 173, [[hep-ex/0206070](#)].
- [26] **DELPHI** Collaboration, J. Abdallah et al., *Search for single top production via FCNC at LEP at $\sqrt{s} = 189$ GeV - 208 GeV*, Phys. Lett. **B590** (2004) 21, [[hep-ex/0404014](#)].
- [27] **OPAL** Collaboration, G. Abbiendi et al., *Search for single top quark production at LEP2*, Phys. Lett. **B521** (2001) 181, [[hep-ex/0110009](#)].
- [28] **L3** Collaboration, P. Achard et al., *Search for single top production at LEP*, Phys. Lett. **B549** (2002) 290, [[hep-ex/0210041](#)].
- [29] The LEP Exotica WG, *Search for single top production via flavour changing neutral currents: preliminary combined results of the LEP experiments*, [LEP Exotica WG 2001-01](#).
- [30] M. Beneke et al., *Top quark physics*, in: *Proceedings of the 1999 CERN Workshop on SM physics (and more) at the LHC*, [hep-ph/0003033](#).
- [31] **ZEUS** Collaboration, H. Abramowicz et al., *Search for single-top production in ep collisions at HERA*, Phys.Lett. **B708** (2012) 27, [[arXiv:1111.3901](#)].
- [32] **H1** Collaboration, A. Aktas et al., *Search for single top quark production in ep collisions at HERA*, Eur. Phys. J. **C33** (2004) 9, [[hep-ex/0310032](#)].
- [33] **ATLAS** Collaboration, *Search for FCNC single top-quark production at with the ATLAS detector*, Phys. Lett. **B712** (2012) 351, [[arXiv:1203.0529](#)].
- [34] **ATLAS** Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, JINST **3** (2008) S08003.
- [35] **ATLAS** Collaboration, *Luminosity Determination in pp Collisions at $\sqrt{s}=7$ TeV using the ATLAS Detector at the LHC*, Eur. Phys. J. **C71** (2011) 1630, [[arXiv:1101.2185](#)].
- [36] **ATLAS** Collaboration, *Luminosity Determination in pp Collisions at $\sqrt{s}=7$ TeV using the ATLAS Detector in 2011*, ATLAS-CONF-2011-116 [<http://cdsweb.cern.ch/record/1376384>].
- [37] S. Agostinelli et al., *GEANT4-a simulation toolkit*, Nucl. Instr. Meth. **A506** (2003) 250.
- [38] **ATLAS** Collaboration, *The ATLAS simulation infrastructure*, Eur. Phys. J. **C70** (2010) 823, [[arXiv:1005.4568](#)].

- [39] S. R. Slabospitsky and L. Sonnenschein, *TopReX generator (version 3.25): Short manual*, *Comput. Phys. Commun.* **148** (2002) 87–102, [[hep-ph/0201292](#)].
- [40] A. Sherstnev and R. Thorne, *Parton Distributions for LO Generators*, *Eur. Phys. J.* **C55** (2008) 553, [[arXiv:0711.2473](#)].
- [41] T. Sjostrand, S. Mrenna, and P. Skands, *PYTHIA 6.4 physics and manual*, *JHEP* **05** (2006) 026, [[hep-ph/0603175](#)].
- [42] B. P. Kersevan and E. Richter-Was, *The Monte Carlo event generator AcerMC version 2.0 with interfaces to PYTHIA 6.2 and HERWIG 6.5*, [hep-ph/0405247](#).
- [43] P. Skands, *Tuning Monte Carlo Generators: The Perugia Tunes*, *Phys. Rev.* **D82** (2010) 074018.
- [44] M. L. Mangano, M. Moretti, F. Piccinini, R. Pittau, and A. D. Polosa, *ALPGEN, a generator for hard multiparton processes in hadronic collisions*, *JHEP* **07** (2003) 001.
- [45] J. Pumplin et al., *New generation of parton distributions with uncertainties from global QCD analysis*, *JHEP* **07** (2002) 012.
- [46] G. Corcella et al., *HERWIG 6.5: an event generator for Hadron Emission Reactions With Interfering Gluons (including supersymmetric processes)*, *JHEP* **01** (2001) 010.
- [47] G. Corcella et al., *HERWIG 6.5 release note*, [hep-ph/0210213](#).
- [48] J. M. Butterworth, J. R. Forshaw, and M. H. Seymour, *Multiparton interactions in photoproduction at HERA*, *Z. Phys.* **C72** (1996) 637, [[hep-ph/9601371](#)].
- [49] **ATLAS** Collaboration, *First tuning of HERWIG/JIMMY to ATLAS data*, [ATLAS-PHYS-PUB-2010-014](#).
- [50] S. Frixione and B. R. Webber, *Matching NLO QCD computations and parton shower simulations*, *JHEP* **06** (2002) 029, [[hep-ph/0204244](#)].
- [51] S. Frixione, P. Nason, and B. R. Webber, *Matching NLO QCD and parton showers in heavy flavour production*, *JHEP* **08** (2003) 007, [[hep-ph/0305252](#)].
- [52] S. Frixione, E. Laenen, P. Motylinski, and B. R. Webber, *Single-top production in MC@NLO*, *JHEP* **03** (2006) 092, [[hep-ph/0512250](#)].
- [53] P. M. Nadolsky et al., *Implications of CTEQ global analysis for collider observables*, *Phys.Rev.* **D78** (2008) 013004, [[arXiv:0802.0007](#)].
- [54] P. M. Nadolsky et al., *Implications of CTEQ global analysis for collider observables*, *Phys. Rev.* **D78** (2008) 013004, [[arXiv:0802.0007](#)].
- [55] M. Aliev et al., *HATHOR – HAdronic Top and Heavy quarks crOss section calculatoR*, *Comput. Phys. Commun.* **182** (2011) 1034.
- [56] N. Kidonakis, *Next-to-next-to-leading-order collinear and soft gluon corrections for t-channel single top quark production*, *Phys. Rev.* **D83** (2011) 091503, [[arXiv:1103.2792](#)].
- [57] N. Kidonakis, *NNLL resummation for s-channel single top quark production*, *Phys. Rev.* **D81** (2010) 054028.
- [58] N. Kidonakis, *Two-loop soft anomalous dimensions for single top quark associated production with a W- or H-*, *Phys. Rev.* **D82** (2010) 054018.
- [59] J. Alwall et al., *MadGraph/MadEvent v4: The New Web Generation*, *JHEP* **0709** (2007) 028, [[arXiv:0706.2334](#)].

- [60] **ATLAS** Collaboration, *Measurement of the cross section for top-quark pair production in pp collisions at $\sqrt{s}=7$ TeV with the ATLAS detector using final states with two high- p_T leptons*, JHEP **1205** (2012) 059, [[arXiv:1202.4892](#)].
- [61] **ATLAS** Collaboration, *Electron performance measurements with the ATLAS detector using the 2010 LHC proton-proton collision data*, Eur. Phys. J. **C72** (2012) 1909, [[arXiv:1110.3174](#)].
- [62] M. Cacciari, G. P. Salam, and G. Soyez, *The anti- k_t jet clustering algorithm*, JHEP **0804** (2008) 063.
- [63] **ATLAS** Collaboration, *Jet energy measurement with the ATLAS detector in proton-proton collisions at $\sqrt{s} = 7$ TeV*, Submitted to Eur. Phys. J. [[arXiv:1112.6426](#)].
- [64] **ATLAS** Collaboration, *Commissioning of the ATLAS high-performance b-tagging algorithms in the 7 TeV collision data*, ATLAS-CONF-2011-102 [<http://cdsweb.cern.ch/record/1369219>].
- [65] **ATLAS** Collaboration, *Performance of missing transverse momentum reconstruction in proton-proton collisions at 7 TeV with ATLAS*, Eur. Phys. J. **C72** (2012) 1844, [[arXiv:1108.5602](#)].
- [66] **ATLAS** Collaboration, *Measurement of the top quark-pair production cross-section with ATLAS in pp collisions at $\sqrt{s} = 7$ TeV*, Eur. Phys. J. **C71** (2011) 1577, [[arXiv:1012.1792](#)].
- [67] G. J. Feldman and R. Cousins, *A unified approach to the classical statistical analysis of small signals*, Phys. Rev. **D57** (1998) 3873, [[physics/9711021](#)].
- [68] F. A. Berends, H. Kuijf, B. Tausk, and W. T. Giele, *On the Production of a W and Jets at Hadron Colliders*, Nucl. Phys. **B357** (1991) 32.
- [69] S. D. Ellis, R. Kleiss, and W. J. Stirling, *W's, Z's and Jets*, Phys. Lett. **B154** (1985) 435.
- [70] J. M. Campbell and R. K. Ellis, *MCFM for the Tevatron and the LHC*, Nucl. Phys. Proc. Suppl. **205** (2010) 10.
- [71] T. Junk, *Confidence Level Computation for Combining Searches with Small Statistics*, Nucl. Instrum. Meth. **A434** (1999) 435, [[hep-ex/9902006](#)].
- [72] A. L. Read, *Modified frequentist analysis of search results (The $CL(s)$ method)*, CERN-OPEN-2000-205. Prepared for Workshop on Confidence Limits, Geneva, Switzerland, 17-18 Jan 2000.
- [73] U. Langenfeld, S. Moch, and P. Uwer, *New Results for $t\bar{t}$ Production at Hadron Colliders*, in *XVII International Workshop on Deep-Inelastic Scattering and Related Topics, Madrid, Spain*, April, 2009.

The ATLAS Collaboration

G. Aad⁴⁸, B. Abbott¹¹¹, J. Abdallah¹¹, S. Abdel Khalek¹¹⁵, A.A. Abdelalim⁴⁹,
O. Abidinov¹⁰, B. Abi¹¹², M. Abolins⁸⁸, O.S. AbouZeid¹⁵⁸, H. Abramowicz¹⁵³,
H. Abreu¹³⁶, E. Acerbi^{89a,89b}, B.S. Acharya^{164a,164b}, L. Adamczyk³⁷, D.L. Adams²⁴,
T.N. Addy⁵⁶, J. Adelman¹⁷⁶, S. Adomeit⁹⁸, P. Adragna⁷⁵, T. Adye¹²⁹, S. Aefsky²²,
J.A. Aguilar-Saavedra^{124b,a}, M. Agustoni¹⁶, M. Aharrouche⁸¹, S.P. Ahlen²¹, F. Ahles⁴⁸,
A. Ahmad¹⁴⁸, M. Ahsan⁴⁰, G. Aielli^{133a,133b}, T. Akdogan^{18a}, T.P.A. Åkesson⁷⁹,
G. Akimoto¹⁵⁵, A.V. Akimov⁹⁴, M.S. Alam¹, M.A. Alam⁷⁶, J. Albert¹⁶⁹, S. Albrand⁵⁵,
M. Aleksa²⁹, I.N. Aleksandrov⁶⁴, F. Alessandria^{89a}, C. Alexa^{25a}, G. Alexander¹⁵³,
G. Alexandre⁴⁹, T. Alexopoulos⁹, M. Alhroob^{164a,164c}, M. Aliev¹⁵, G. Alimonti^{89a},
J. Alison¹²⁰, B.M.M. Allbrooke¹⁷, P.P. Allport⁷³, S.E. Allwood-Spiers⁵³, J. Almond⁸²,
A. Aloisio^{102a,102b}, R. Alon¹⁷², A. Alonso⁷⁹, B. Alvarez Gonzalez⁸⁸, M.G. Alviggi^{102a,102b},
K. Amako⁶⁵, C. Amelung²², V.V. Ammosov¹²⁸, A. Amorim^{124a,b}, N. Amram¹⁵³,
C. Anastopoulos²⁹, L.S. Ancu¹⁶, N. Andari¹¹⁵, T. Andeen³⁴, C.F. Anders^{58b},
G. Anders^{58a}, K.J. Anderson³⁰, A. Andreazza^{89a,89b}, V. Andrei^{58a}, X.S. Anduaga⁷⁰,
P. Anger⁴³, A. Angerami³⁴, F. Anghinolfi²⁹, A. Anisenkov¹⁰⁷, N. Anjos^{124a}, A. Annovi⁴⁷,
A. Antonaki⁸, M. Antonelli⁴⁷, A. Antonov⁹⁶, J. Antos^{144b}, F. Anulli^{132a}, S. Aoun⁸³,
L. Aperio Bella⁴, R. Apolle^{118,c}, G. Arabidze⁸⁸, I. Aracena¹⁴³, Y. Arai⁶⁵, A.T.H. Arce⁴⁴,
S. Arfaoui¹⁴⁸, J-F. Arguin¹⁴, E. Arik^{18a,*}, M. Arik^{18a}, A.J. Armbruster⁸⁷, O. Arnaez⁸¹,
V. Arnal⁸⁰, C. Arnault¹¹⁵, A. Artamonov⁹⁵, G. Artoni^{132a,132b}, D. Arutinov²⁰, S. Asai¹⁵⁵,
R. Asfandiyarov¹⁷³, S. Ask²⁷, B. Åsman^{146a,146b}, L. Asquith⁵, K. Assamagan²⁴,
A. Astbury¹⁶⁹, B. Aubert⁴, E. Auge¹¹⁵, K. Augsten¹²⁷, M. Aurousseau^{145a}, G. Avolio¹⁶³,
R. Avramidou⁹, D. Axen¹⁶⁸, G. Azuelos^{93,d}, Y. Azuma¹⁵⁵, M.A. Baak²⁹,
G. Baccaglioni^{89a}, C. Bacci^{134a,134b}, A.M. Bach¹⁴, H. Bachacou¹³⁶, K. Bachas²⁹,
M. Backes⁴⁹, M. Backhaus²⁰, E. Badescu^{25a}, P. Bagnaia^{132a,132b}, S. Bahinipati²,
Y. Bai^{32a}, D.C. Bailey¹⁵⁸, T. Bain¹⁵⁸, J.T. Baines¹²⁹, O.K. Baker¹⁷⁶, M.D. Baker²⁴,
S. Baker⁷⁷, E. Banas³⁸, P. Banerjee⁹³, Sw. Banerjee¹⁷³, D. Banfi²⁹, A. Bangert¹⁵⁰,
V. Bansal¹⁶⁹, H.S. Bansil¹⁷, L. Barak¹⁷², S.P. Baranov⁹⁴, A. Barbaro Galtieri¹⁴,
T. Barber⁴⁸, E.L. Barberio⁸⁶, D. Barberis^{50a,50b}, M. Barbero²⁰, D.Y. Bardin⁶⁴,
T. Barillari⁹⁹, M. Barisonzi¹⁷⁵, T. Barklow¹⁴³, N. Barlow²⁷, B.M. Barnett¹²⁹,
R.M. Barnett¹⁴, A. Baroncelli^{134a}, G. Barone⁴⁹, A.J. Barr¹¹⁸, F. Barreiro⁸⁰, J. Barreiro
Guimarães da Costa⁵⁷, P. Barrillon¹¹⁵, R. Bartoldus¹⁴³, A.E. Barton⁷¹, V. Bartsch¹⁴⁹,
R.L. Bates⁵³, L. Batkova^{144a}, J.R. Batley²⁷, A. Battaglia¹⁶, M. Battistin²⁹, F. Bauer¹³⁶,
H.S. Bawa^{143,e}, S. Beale⁹⁸, T. Beau⁷⁸, P.H. Beauchemin¹⁶¹, R. Beccherle^{50a}, P. Bechtel²⁰,
H.P. Beck¹⁶, A.K. Becker¹⁷⁵, S. Becker⁹⁸, M. Beckingham¹³⁸, K.H. Becks¹⁷⁵,
A.J. Beddall^{18c}, A. Beddall^{18c}, S. Bedikian¹⁷⁶, V.A. Bednyakov⁶⁴, C.P. Bee⁸³, M. Begel²⁴,
S. Behar Harpaz¹⁵², M. Beimforde⁹⁹, C. Belanger-Champagne⁸⁵, P.J. Bell⁴⁹, W.H. Bell⁴⁹,
G. Bella¹⁵³, L. Bellagamba^{19a}, F. Bellina²⁹, M. Bellomo²⁹, A. Belloni⁵⁷,
O. Beloborodova^{107,f}, K. Belotskiy⁹⁶, O. Beltramello²⁹, O. Benary¹⁵³,
D. Bencheikroun^{135a}, K. Bendtz^{146a,146b}, N. Benekos¹⁶⁵, Y. Benhammou¹⁵³,
E. Benhar Noccioli⁴⁹, J.A. Benitez Garcia^{159b}, D.P. Benjamin⁴⁴, M. Benoit¹¹⁵,
J.R. Bensinger²², K. Benslama¹³⁰, S. Bentvelsen¹⁰⁵, D. Berge²⁹,

E. Bergeaas Kuutmann⁴¹, N. Berger⁴, F. Berghaus¹⁶⁹, E. Berglund¹⁰⁵, J. Beringer¹⁴,
 P. Bernat⁷⁷, R. Bernhard⁴⁸, C. Bernius²⁴, T. Berry⁷⁶, C. Bertella⁸³, A. Bertin^{19a,19b},
 F. Bertolucci^{122a,122b}, M.I. Besana^{89a,89b}, G.J. Besjes¹⁰⁴, N. Besson¹³⁶, S. Bethke⁹⁹,
 W. Bhimji⁴⁵, R.M. Bianchi²⁹, M. Bianco^{72a,72b}, O. Biebel⁹⁸, S.P. Bieniek⁷⁷,
 K. Bierwagen⁵⁴, J. Biesiada¹⁴, M. Biglietti^{134a}, H. Bilokon⁴⁷, M. Bindi^{19a,19b}, S. Binet¹¹⁵,
 A. Bingul^{18c}, C. Bini^{132a,132b}, C. Biscarat¹⁷⁸, U. Bitenc⁴⁸, K.M. Black²¹, R.E. Blair⁵,
 J.-B. Blanchard¹³⁶, G. Blanchot²⁹, T. Blazek^{144a}, C. Blocker²², J. Blocki³⁸, A. Blondel⁴⁹,
 W. Blum⁸¹, U. Blumenschein⁵⁴, G.J. Bobbink¹⁰⁵, V.B. Bobrovnikov¹⁰⁷, S.S. Bocchetta⁷⁹,
 A. Bocci⁴⁴, C.R. Boddy¹¹⁸, M. Boehler⁴¹, J. Boek¹⁷⁵, N. Boelaert³⁵, J.A. Bogaerts²⁹,
 A. Bogdanchikov¹⁰⁷, A. Bogouch^{90,*}, C. Bohm^{146a}, J. Bohm¹²⁵, V. Boisvert⁷⁶, T. Bold³⁷,
 V. Boldea^{25a}, N.M. Bolnet¹³⁶, M. Bomben⁷⁸, M. Bona⁷⁵, M. Boonekamp¹³⁶,
 C.N. Booth¹³⁹, S. Bordini⁷⁸, C. Borer¹⁶, A. Borisov¹²⁸, G. Borissov⁷¹, I. Borjanovic^{12a},
 M. Borri⁸², S. Borroni⁸⁷, V. Bortolotto^{134a,134b}, K. Bos¹⁰⁵, D. Boscherini^{19a},
 M. Bosman¹¹, H. Boterenbrood¹⁰⁵, D. Botterill¹²⁹, J. Bouchami⁹³, J. Boudreau¹²³,
 E.V. Bouhova-Thacker⁷¹, D. Boumediene³³, C. Bourdarios¹¹⁵, N. Bousson⁸³, A. Boveia³⁰,
 J. Boyd²⁹, I.R. Boyko⁶⁴, I. Bozovic-Jelisavcic^{12b}, J. Bracinik¹⁷, P. Branchini^{134a},
 A. Brandt⁷, G. Brandt¹¹⁸, O. Brandt⁵⁴, U. Bratzler¹⁵⁶, B. Brau⁸⁴, J.E. Brau¹¹⁴,
 H.M. Braun¹⁷⁵, S.F. Brazzale^{164a,164c}, B. Breliev¹⁵⁸, J. Bremer²⁹, K. Brendlinger¹²⁰,
 R. Brenner¹⁶⁶, S. Bressler¹⁷², D. Britton⁵³, F.M. Brochu²⁷, I. Brock²⁰, R. Brock⁸⁸,
 E. Brodet¹⁵³, F. Broggi^{89a}, C. Bromberg⁸⁸, J. Bronner⁹⁹, G. Brooijmans³⁴, T. Brooks⁷⁶,
 W.K. Brooks^{31b}, G. Brown⁸², H. Brown⁷, P.A. Bruckman de Renstrom³⁸, D. Bruncko^{144b},
 R. Bruneliere⁴⁸, S. Brunet⁶⁰, A. Bruni^{19a}, G. Bruni^{19a}, M. Bruschi^{19a}, T. Buanes¹³,
 Q. Buat⁵⁵, F. Bucci⁴⁹, J. Buchanan¹¹⁸, P. Buchholz¹⁴¹, R.M. Buckingham¹¹⁸,
 A.G. Buckley⁴⁵, S.I. Buda^{25a}, I.A. Budagov⁶⁴, B. Budick¹⁰⁸, V. Büscher⁸¹, L. Bugge¹¹⁷,
 O. Bulekov⁹⁶, A.C. Bundock⁷³, M. Bunse⁴², T. Buran¹¹⁷, H. Burckhart²⁹, S. Burdin⁷³,
 T. Burgess¹³, S. Burke¹²⁹, E. Busato³³, P. Bussey⁵³, C.P. Buszello¹⁶⁶, B. Butler¹⁴³,
 J.M. Butler²¹, C.M. Buttar⁵³, J.M. Butterworth⁷⁷, W. Buttinger²⁷, S. Cabrera Urbán¹⁶⁷,
 D. Caforio^{19a,19b}, O. Cakir^{3a}, P. Calafiura¹⁴, G. Calderini⁷⁸, P. Calfayan⁹⁸, R. Calkins¹⁰⁶,
 L.P. Caloba^{23a}, R. Caloi^{132a,132b}, D. Calvet³³, S. Calvet³³, R. Camacho Toro³³,
 P. Camarri^{133a,133b}, D. Cameron¹¹⁷, L.M. Caminada¹⁴, S. Campana²⁹, M. Campanelli⁷⁷,
 V. Canale^{102a,102b}, F. Canelli^{30,g}, A. Canepa^{159a}, J. Cantero⁸⁰, R. Cantrill⁷⁶,
 L. Capasso^{102a,102b}, M.D.M. Capeans Garrido²⁹, I. Caprini^{25a}, M. Caprini^{25a},
 D. Capriotti⁹⁹, M. Capua^{36a,36b}, R. Caputo⁸¹, R. Cardarelli^{133a}, T. Carli²⁹,
 G. Carlino^{102a}, L. Carminati^{89a,89b}, B. Caron⁸⁵, S. Caron¹⁰⁴, E. Carquin^{31b},
 G.D. Carrillo Montoya¹⁷³, A.A. Carter⁷⁵, J.R. Carter²⁷, J. Carvalho^{124a,h}, D. Casadei¹⁰⁸,
 M.P. Casado¹¹, M. Cascella^{122a,122b}, C. Caso^{50a,50b,*}, A.M. Castaneda Hernandez^{173,i},
 E. Castaneda-Miranda¹⁷³, V. Castillo Gimenez¹⁶⁷, N.F. Castro^{124a}, G. Cataldi^{72a},
 P. Catastini⁵⁷, A. Catinaccio²⁹, J.R. Catmore²⁹, A. Cattai²⁹, G. Cattani^{133a,133b},
 S. Caughron⁸⁸, P. Cavalleri⁷⁸, D. Cavalli^{89a}, M. Cavalli-Sforza¹¹, V. Cavasinni^{122a,122b},
 F. Ceradini^{134a,134b}, A.S. Cerqueira^{23b}, A. Cerri²⁹, L. Cerrito⁷⁵, F. Cerutti⁴⁷,
 S.A. Cetin^{18b}, A. Chafaq^{135a}, D. Chakraborty¹⁰⁶, I. Chalupkova¹²⁶, K. Chan²,
 B. Chapleau⁸⁵, J.D. Chapman²⁷, J.W. Chapman⁸⁷, E. Chareyre⁷⁸, D.G. Charlton¹⁷,
 V. Chavda⁸², C.A. Chavez Barajas²⁹, S. Cheatham⁸⁵, S. Chekanov⁵, S.V. Chekulaev^{159a},

G.A. Chelkov⁶⁴, M.A. Chelstowska¹⁰⁴, C. Chen⁶³, H. Chen²⁴, S. Chen^{32c}, X. Chen¹⁷³, Y. Chen³⁴, A. Cheplakov⁶⁴, R. Cherkaoui El Moursli^{135e}, V. Chernyatin²⁴, E. Cheu⁶, S.L. Cheung¹⁵⁸, L. Chevalier¹³⁶, G. Chiefari^{102a,102b}, L. Chikovani^{51a}, J.T. Childers²⁹, A. Chilingarov⁷¹, G. Chiodini^{72a}, A.S. Chisholm¹⁷, R.T. Chislett⁷⁷, A. Chitan^{25a}, M.V. Chizhov⁶⁴, G. Choudalakis³⁰, S. Chouridou¹³⁷, I.A. Christidi⁷⁷, A. Christov⁴⁸, D. Chromek-Burckhart²⁹, M.L. Chu¹⁵¹, J. Chudoba¹²⁵, G. Ciapetti^{132a,132b}, A.K. Ciftci^{3a}, R. Ciftci^{3a}, D. Cinca³³, V. Cindro⁷⁴, C. Ciocca^{19a,19b}, A. Ciocio¹⁴, M. Cirilli⁸⁷, P. Cirkovic^{12b}, M. Citterio^{89a}, M. Ciubancan^{25a}, A. Clark⁴⁹, P.J. Clark⁴⁵, R.N. Clarke¹⁴, W. Cleland¹²³, J.C. Clemens⁸³, B. Clement⁵⁵, C. Clement^{146a,146b}, Y. Coadou⁸³, M. Cobal^{164a,164c}, A. Coccaro¹³⁸, J. Cochran⁶³, J.G. Cogan¹⁴³, J. Coggeshall¹⁶⁵, E. Cogneras¹⁷⁸, J. Colas⁴, A.P. Colijn¹⁰⁵, N.J. Collins¹⁷, C. Collins-Tooth⁵³, J. Collot⁵⁵, T. Colombo^{119a,119b}, G. Colon⁸⁴, P. Conde Muiño^{124a}, E. Coniavitis¹¹⁸, M.C. Conidi¹¹, S.M. Consonni^{89a,89b}, V. Consorti⁴⁸, S. Constantinescu^{25a}, C. Conta^{119a,119b}, G. Conti⁵⁷, F. Conventi^{102a,j}, M. Cooke¹⁴, B.D. Cooper⁷⁷, A.M. Cooper-Sarkar¹¹⁸, K. Copic¹⁴, T. Cornelissen¹⁷⁵, M. Corradi^{19a}, F. Corriveau^{85,k}, A. Cortes-Gonzalez¹⁶⁵, G. Cortiana⁹⁹, G. Costa^{89a}, M.J. Costa¹⁶⁷, D. Costanzo¹³⁹, T. Costin³⁰, D. Côté²⁹, L. Courneyea¹⁶⁹, G. Cowan⁷⁶, C. Cowden²⁷, B.E. Cox⁸², K. Cranmer¹⁰⁸, F. Crescioli^{122a,122b}, M. Cristinziani²⁰, G. Crosetti^{36a,36b}, R. Crupi^{72a,72b}, S. Crépe-Renaudin⁵⁵, C.-M. Cuciuc^{25a}, C. Cuenca Almenar¹⁷⁶, T. Cuhadar Donszelmann¹³⁹, M. Curatolo⁴⁷, C.J. Curtis¹⁷, C. Cuthbert¹⁵⁰, P. Cwetanski⁶⁰, H. Czirr¹⁴¹, P. Czodrowski⁴³, Z. Czyczula¹⁷⁶, S. D'Auria⁵³, M. D'Onofrio⁷³, A. D'Orazio^{132a,132b}, M.J. Da Cunha Sargedas De Sousa^{124a}, C. Da Via⁸², W. Dabrowski³⁷, A. Dafinca¹¹⁸, T. Dai⁸⁷, C. Dallapiccola⁸⁴, M. Dam³⁵, M. Dameri^{50a,50b}, D.S. Damiani¹³⁷, H.O. Danielsson²⁹, V. Dao⁴⁹, G. Darbo^{50a}, G.L. Darlea^{25b}, W. Davey²⁰, T. Davidek¹²⁶, N. Davidson⁸⁶, R. Davidson⁷¹, E. Davies^{118,c}, M. Davies⁹³, A.R. Davison⁷⁷, Y. Davygora^{58a}, E. Dawe¹⁴², I. Dawson¹³⁹, R.K. Daya-Ishmukhametova²², K. De⁷, R. de Asmundis^{102a}, S. De Castro^{19a,19b}, S. De Cecco⁷⁸, J. de Graat⁹⁸, N. De Groot¹⁰⁴, P. de Jong¹⁰⁵, C. De La Taille¹¹⁵, H. De la Torre⁸⁰, F. De Lorenzi⁶³, L. de Mora⁷¹, L. De Noij¹⁰⁵, D. De Pedis^{132a}, A. De Salvo^{132a}, U. De Sanctis^{164a,164c}, A. De Santo¹⁴⁹, J.B. De Vivie De Regie¹¹⁵, G. De Zorzi^{132a,132b}, W.J. Dearnaley⁷¹, R. Debbe²⁴, C. Debenedetti⁴⁵, B. Dechenaux⁵⁵, D.V. Dedovich⁶⁴, J. Degenhardt¹²⁰, C. Del Papa^{164a,164c}, J. Del Peso⁸⁰, T. Del Prete^{122a,122b}, T. Delemontex⁵⁵, M. Deliyergiyev⁷⁴, A. Dell'Acqua²⁹, L. Dell'Asta²¹, M. Della Pietra^{102a,j}, D. della Volpe^{102a,102b}, M. Delmastro⁴, P.A. Delsart⁵⁵, C. Deluca¹⁰⁵, S. Demers¹⁷⁶, M. Demichev⁶⁴, B. Demirkoz^{11,l}, J. Deng¹⁶³, S.P. Denisov¹²⁸, D. Derendarz³⁸, J.E. Derkaoui^{135d}, F. Derue⁷⁸, P. Dervan⁷³, K. Desch²⁰, E. Devetak¹⁴⁸, P.O. Deviveiros¹⁰⁵, A. Dewhurst¹²⁹, B. DeWilde¹⁴⁸, S. Dhaliwal¹⁵⁸, R. Dhullipudi^{24,m}, A. Di Ciaccio^{133a,133b}, L. Di Ciaccio⁴, A. Di Girolamo²⁹, B. Di Girolamo²⁹, S. Di Luise^{134a,134b}, A. Di Mattia¹⁷³, B. Di Micco²⁹, R. Di Nardo⁴⁷, A. Di Simone^{133a,133b}, R. Di Sipio^{19a,19b}, M.A. Diaz^{31a}, E.B. Diehl⁸⁷, J. Dietrich⁴¹, T.A. Dietzsch^{58a}, S. Diglio⁸⁶, K. Dindar Yagci³⁹, J. Dingfelder²⁰, F. Dinut^{25a}, C. Dionisi^{132a,132b}, P. Dita^{25a}, S. Dita^{25a}, F. Dittus²⁹, F. Djama⁸³, T. Djobava^{51b}, M.A.B. do Vale^{23c}, A. Do Valle Wemans^{124a,n}, T.K.O. Doan⁴, M. Dobbbs⁸⁵, R. Dobinson^{29,*}, D. Dobos²⁹, E. Dobson^{29,o}, J. Dodd³⁴,

C. Doglioni⁴⁹, T. Doherty⁵³, Y. Doi^{65,*}, J. Dolejsi¹²⁶, I. Dolenc⁷⁴, Z. Dolezal¹²⁶,
 B.A. Dolgoshein^{96,*}, T. Dohmae¹⁵⁵, M. Donadelli^{23d}, J. Donini³³, J. Dopke²⁹,
 A. Doria^{102a}, A. Dos Anjos¹⁷³, A. Dotti^{122a,122b}, M.T. Dova⁷⁰, A.D. Doxiadis¹⁰⁵,
 A.T. Doyle⁵³, M. Dris⁹, J. Dubbert⁹⁹, S. Dube¹⁴, E. Duchovni¹⁷², G. Duckeck⁹⁸,
 A. Dudarev²⁹, F. Dudziak⁶³, M. Dührssen²⁹, I.P. Duerdoth⁸², L. Duflot¹¹⁵,
 M-A. Dufour⁸⁵, M. Dunford²⁹, H. Duran Yildiz^{3a}, R. Duxfield¹³⁹, M. Dwuznik³⁷,
 F. Dydak²⁹, M. Düren⁵², J. Ebke⁹⁸, S. Eckweiler⁸¹, K. Edmonds⁸¹, C.A. Edwards⁷⁶,
 N.C. Edwards⁵³, W. Ehrenfeld⁴¹, T. Eifert¹⁴³, G. Eigen¹³, K. Einsweiler¹⁴,
 E. Eisenhandler⁷⁵, T. Ekelof¹⁶⁶, M. El Kacimi^{135c}, M. Ellert¹⁶⁶, S. Elles⁴, F. Ellinghaus⁸¹,
 K. Ellis⁷⁵, N. Ellis²⁹, J. Elmsheuser⁹⁸, M. Elsing²⁹, D. Emeliyanov¹²⁹, R. Engelmann¹⁴⁸,
 A. Engl⁹⁸, B. Epp⁶¹, A. Eppig⁸⁷, J. Erdmann⁵⁴, A. Ereditato¹⁶, D. Eriksson^{146a},
 J. Ernst¹, M. Ernst²⁴, J. Ernwein¹³⁶, D. Errede¹⁶⁵, S. Errede¹⁶⁵, E. Ertel⁸¹,
 M. Escalier¹¹⁵, H. Esch⁴², C. Escobar¹²³, X. Espinal Curull¹¹, B. Esposito⁴⁷, F. Etienne⁸³,
 A.I. Etienvre¹³⁶, E. Etzion¹⁵³, D. Evangelakou⁵⁴, H. Evans⁶⁰, L. Fabbri^{19a,19b}, C. Fabre²⁹,
 R.M. Fakhrutdinov¹²⁸, S. Falciano^{132a}, Y. Fang¹⁷³, M. Fanti^{89a,89b}, A. Farbin⁷,
 A. Farilla^{134a}, J. Farley¹⁴⁸, T. Farooque¹⁵⁸, S. Farrell¹⁶³, S.M. Farrington¹¹⁸,
 P. Farthouat²⁹, P. Fassnacht²⁹, D. Fassouliotis⁸, B. Fatholahzadeh¹⁵⁸, A. Favareto^{89a,89b},
 L. Fayard¹¹⁵, S. Fazio^{36a,36b}, R. Febbraro³³, P. Federic^{144a}, O.L. Fedin¹²¹, W. Fedorko⁸⁸,
 M. Fehling-Kaschek⁴⁸, L. Feligioni⁸³, D. Fellmann⁵, C. Feng^{32d}, E.J. Feng⁵,
 A.B. Fenyuk¹²⁸, J. Ferencei^{144b}, W. Fernando⁵, S. Ferrag⁵³, J. Ferrando⁵³, V. Ferrara⁴¹,
 A. Ferrari¹⁶⁶, P. Ferrari¹⁰⁵, R. Ferrari^{119a}, D.E. Ferreira de Lima⁵³, A. Ferrer¹⁶⁷,
 D. Ferrere⁴⁹, C. Ferretti⁸⁷, A. Ferretto Parodi^{50a,50b}, M. Fiascaris³⁰, F. Fiedler⁸¹,
 A. Filipčič⁷⁴, F. Filthaut¹⁰⁴, M. Fincke-Keeler¹⁶⁹, M.C.N. Fiolhais^{124a,h}, L. Fiorini¹⁶⁷,
 A. Firan³⁹, G. Fischer⁴¹, M.J. Fisher¹⁰⁹, M. Flechl⁴⁸, I. Fleck¹⁴¹, J. Fleckner⁸¹,
 P. Fleischmann¹⁷⁴, S. Fleischmann¹⁷⁵, T. Flick¹⁷⁵, A. Floderus⁷⁹, L.R. Flores Castillo¹⁷³,
 M.J. Flowerdew⁹⁹, T. Fonseca Martin¹⁶, A. Formica¹³⁶, A. Forti⁸², D. Fortin^{159a},
 D. Fournier¹¹⁵, H. Fox⁷¹, P. Francavilla¹¹, S. Franchino^{119a,119b}, D. Francis²⁹, T. Frank¹⁷²,
 S. Franz²⁹, M. Fraternali^{119a,119b}, S. Fratina¹²⁰, S.T. French²⁷, C. Friedrich⁴¹,
 F. Friedrich⁴³, R. Froeschl²⁹, D. Froidevaux²⁹, J.A. Frost²⁷, C. Fukunaga¹⁵⁶,
 E. Fullana Torregrosa²⁹, B.G. Fulson¹⁴³, J. Fuster¹⁶⁷, C. Gabaldon²⁹, O. Gabizon¹⁷²,
 T. Gadfort²⁴, S. Gadomski⁴⁹, G. Gagliardi^{50a,50b}, P. Gagnon⁶⁰, C. Galea⁹⁸,
 E.J. Gallas¹¹⁸, V. Gallo¹⁶, B.J. Gallop¹²⁹, P. Gallus¹²⁵, K.K. Gan¹⁰⁹, Y.S. Gao^{143,e},
 A. Gaponenko¹⁴, F. Garbersen¹⁷⁶, M. Garcia-Sciveres¹⁴, C. García¹⁶⁷, J.E. García
 Navarro¹⁶⁷, R.W. Gardner³⁰, N. Garelli²⁹, H. Garitaonandia¹⁰⁵, V. Garonne²⁹,
 J. Garvey¹⁷, C. Gatti⁴⁷, G. Gaudio^{119a}, B. Gaur¹⁴¹, L. Gauthier¹³⁶, P. Gauzzi^{132a,132b},
 I.L. Gavrilenko⁹⁴, C. Gay¹⁶⁸, G. Gaycken²⁰, E.N. Gazis⁹, P. Ge^{32d}, Z. Gecse¹⁶⁸,
 C.N.P. Gee¹²⁹, D.A.A. Geerts¹⁰⁵, Ch. Geich-Gimbel²⁰, K. Gellerstedt^{146a,146b},
 C. Gemme^{50a}, A. Gemmell⁵³, M.H. Genest⁵⁵, S. Gentile^{132a,132b}, M. George⁵⁴,
 S. George⁷⁶, P. Gerlach¹⁷⁵, A. Gershon¹⁵³, C. Geweniger^{58a}, H. Ghazlane^{135b},
 N. Ghodbane³³, B. Giacobbe^{19a}, S. Giagu^{132a,132b}, V. Giakoumopoulou⁸,
 V. Giangiobbe¹¹, F. Gianotti²⁹, B. Gibbard²⁴, A. Gibson¹⁵⁸, S.M. Gibson²⁹,
 D. Gillberg²⁸, A.R. Gillman¹²⁹, D.M. Gingrich^{2,d}, J. Ginzburg¹⁵³, N. Giokaris⁸,
 M.P. Giordani^{164c}, R. Giordano^{102a,102b}, F.M. Giorgi¹⁵, P. Giovannini⁹⁹, P.F. Giraud¹³⁶,

D. Giugni^{89a}, M. Giunta⁹³, P. Giusti^{19a}, B.K. Gjelsten¹¹⁷, L.K. Gladilin⁹⁷, C. Glasman⁸⁰,
 J. Glatzer⁴⁸, A. Glazov⁴¹, K.W. Glitza¹⁷⁵, G.L. Glonti⁶⁴, J.R. Goddard⁷⁵, J. Godfrey¹⁴²,
 J. Godlewski²⁹, M. Goebel⁴¹, T. Göpfert⁴³, C. Goeringer⁸¹, C. Gössling⁴², S. Goldfarb⁸⁷,
 T. Golling¹⁷⁶, A. Gomes^{124a,b}, L.S. Gomez Fajardo⁴¹, R. Gonçalo⁷⁶,
 J. Goncalves Pinto Firmino Da Costa⁴¹, L. Gonella²⁰, S. Gonzalez¹⁷³, S. González de la
 Hoz¹⁶⁷, G. Gonzalez Parra¹¹, M.L. Gonzalez Silva²⁶, S. Gonzalez-Sevilla⁴⁹,
 J.J. Goodson¹⁴⁸, L. Goossens²⁹, P.A. Gorbounov⁹⁵, H.A. Gordon²⁴, I. Gorelov¹⁰³,
 G. Gorfine¹⁷⁵, B. Gorini²⁹, E. Gorini^{72a,72b}, A. Gorišek⁷⁴, E. Gornicki³⁸, B. Gosdzik⁴¹,
 A.T. Goshaw⁵, M. Gosselink¹⁰⁵, M.I. Gostkin⁶⁴, I. Gough Eschrich¹⁶³, M. Goughri^{135a},
 D. Goujdami^{135c}, M.P. Goulette⁴⁹, A.G. Goussiou¹³⁸, C. Goy⁴, S. Gozpınar²²,
 I. Grabowska-Bold³⁷, P. Grafström^{19a,19b}, K.-J. Grahn⁴¹, F. Grancagnolo^{72a},
 S. Grancagnolo¹⁵, V. Grassi¹⁴⁸, V. Gratchev¹²¹, N. Grau³⁴, H.M. Gray²⁹, J.A. Gray¹⁴⁸,
 E. Graziani^{134a}, O.G. Grebenyuk¹²¹, T. Greenshaw⁷³, Z.D. Greenwood^{24,m},
 K. Gregersen³⁵, I.M. Gregor⁴¹, P. Grenier¹⁴³, J. Griffiths¹³⁸, N. Grigalashvili⁶⁴,
 A.A. Grillo¹³⁷, S. Grinstein¹¹, Y.V. Grishkevich⁹⁷, J.-F. Grivaz¹¹⁵, E. Gross¹⁷²,
 J. Grosse-Knetter⁵⁴, J. Groth-Jensen¹⁷², K. Grybel¹⁴¹, D. Guest¹⁷⁶, C. Guicheney³³,
 A. Guida^{72a,72b}, S. Guindon⁵⁴, U. Gul⁵³, H. Guler^{85,p}, J. Gunther¹²⁵, B. Guo¹⁵⁸,
 J. Guo³⁴, P. Gutierrez¹¹¹, N. Guttman¹⁵³, O. Gutzwiller¹⁷³, C. Guyot¹³⁶, C. Gwenlan¹¹⁸,
 C.B. Gwilliam⁷³, A. Haas¹⁴³, S. Haas²⁹, C. Haber¹⁴, H.K. Hadavand³⁹, D.R. Hadley¹⁷,
 P. Haefner²⁰, F. Hahn²⁹, S. Haider²⁹, Z. Hajduk³⁸, H. Hakobyan¹⁷⁷, D. Hall¹¹⁸,
 J. Haller⁵⁴, K. Hamacher¹⁷⁵, P. Hamal¹¹³, M. Hamer⁵⁴, A. Hamilton^{145b,q}, S. Hamilton¹⁶¹,
 L. Han^{32b}, K. Hanagaki¹¹⁶, K. Hanawa¹⁶⁰, M. Hance¹⁴, C. Handel⁸¹, P. Hanke^{58a},
 J.R. Hansen³⁵, J.B. Hansen³⁵, J.D. Hansen³⁵, P.H. Hansen³⁵, P. Hansson¹⁴³, K. Hara¹⁶⁰,
 G.A. Hare¹³⁷, T. Harenberg¹⁷⁵, S. Harkusha⁹⁰, D. Harper⁸⁷, R.D. Harrington⁴⁵,
 O.M. Harris¹³⁸, J. Hartert⁴⁸, F. Hartjes¹⁰⁵, T. Haruyama⁶⁵, A. Harvey⁵⁶, S. Hasegawa¹⁰¹,
 Y. Hasegawa¹⁴⁰, S. Hassani¹³⁶, S. Haug¹⁶, M. Hauschild²⁹, R. Hauser⁸⁸, M. Havranek²⁰,
 C.M. Hawkes¹⁷, R.J. Hawkings²⁹, A.D. Hawkins⁷⁹, D. Hawkins¹⁶³, T. Hayakawa⁶⁶,
 T. Hayashi¹⁶⁰, D. Hayden⁷⁶, C.P. Hays¹¹⁸, H.S. Hayward⁷³, S.J. Haywood¹²⁹, M. He^{32d},
 S.J. Head¹⁷, V. Hedberg⁷⁹, L. Heelan⁷, S. Heim⁸⁸, B. Heinemann¹⁴, S. Heisterkamp³⁵,
 L. Helary²¹, C. Heller⁹⁸, M. Heller²⁹, S. Hellman^{146a,146b}, D. Hellmich²⁰, C. Helsen¹¹,
 R.C.W. Henderson⁷¹, M. Henke^{58a}, A. Henrichs⁵⁴, A.M. Henriques Correia²⁹,
 S. Henrot-Versille¹¹⁵, C. Hensel⁵⁴, T. Henß¹⁷⁵, C.M. Hernandez⁷, Y. Hernández
 Jiménez¹⁶⁷, R. Herrberg¹⁵, G. Herten⁴⁸, R. Hertenberger⁹⁸, L. Hervas²⁹, G.G. Hesketh⁷⁷,
 N.P. Hessey¹⁰⁵, E. Higón-Rodríguez¹⁶⁷, J.C. Hill²⁷, K.H. Hiller⁴¹, S. Hillert²⁰,
 S.J. Hillier¹⁷, I. Hinchliffe¹⁴, E. Hines¹²⁰, M. Hirose¹¹⁶, F. Hirsch⁴², D. Hirschbuehl¹⁷⁵,
 J. Hobbs¹⁴⁸, N. Hod¹⁵³, M.C. Hodgkinson¹³⁹, P. Hodgson¹³⁹, A. Hoecker²⁹,
 M.R. Hoferkamp¹⁰³, J. Hoffman³⁹, D. Hoffmann⁸³, M. Hohlfeld⁸¹, M. Holder¹⁴¹,
 S.O. Holmgren^{146a}, T. Holy¹²⁷, J.L. Holzbauer⁸⁸, T.M. Hong¹²⁰,
 L. Hooft van Huysduynen¹⁰⁸, C. Horn¹⁴³, S. Horner⁴⁸, J.-Y. Hostachy⁵⁵, S. Hou¹⁵¹,
 A. Hoummada^{135a}, J. Howard¹¹⁸, J. Howarth⁸², I. Hristova¹⁵, J. Hrivnac¹¹⁵,
 T. Hryn'ova⁴, P.J. Hsu⁸¹, S.-C. Hsu¹⁴, Z. Hubacek¹²⁷, F. Hubaut⁸³, F. Huegging²⁰,
 A. Huettmann⁴¹, T.B. Huffman¹¹⁸, E.W. Hughes³⁴, G. Hughes⁷¹, M. Huhtinen²⁹,
 M. Hurwitz¹⁴, U. Husemann⁴¹, N. Huseynov^{64,r}, J. Huston⁸⁸, J. Huth⁵⁷, G. Iacobucci⁴⁹,

G. Iakovidis⁹, M. Ibbotson⁸², I. Ibragimov¹⁴¹, L. Iconomidou-Fayard¹¹⁵, J. Idarraga¹¹⁵, P. Iengo^{102a}, O. Igonkina¹⁰⁵, Y. Ikegami⁶⁵, M. Ikeno⁶⁵, D. Iliadis¹⁵⁴, N. Ilic¹⁵⁸, T. Ince²⁰, J. Inigo-Golfin²⁹, P. Ioannou⁸, M. Iodice^{134a}, K. Iordanidou⁸, V. Ippolito^{132a,132b}, A. Irles Quiles¹⁶⁷, C. Isaksson¹⁶⁶, M. Ishino⁶⁷, M. Ishitsuka¹⁵⁷, R. Ishmukhametov³⁹, C. Issever¹¹⁸, S. Istin^{18a}, A.V. Ivashin¹²⁸, W. Iwanski³⁸, H. Iwasaki⁶⁵, J.M. Izen⁴⁰, V. Izzo^{102a}, B. Jackson¹²⁰, J.N. Jackson⁷³, P. Jackson¹⁴³, M.R. Jaekel²⁹, V. Jain⁶⁰, K. Jakobs⁴⁸, S. Jakobsen³⁵, T. Jakoubek¹²⁵, J. Jakubek¹²⁷, D.K. Jana¹¹¹, E. Jansen⁷⁷, H. Jansen²⁹, A. Jantsch⁹⁹, M. Janus⁴⁸, G. Jarlskog⁷⁹, L. Jeanty⁵⁷, I. Jen-La Plante³⁰, P. Jenni²⁹, A. Jeremie⁴, P. Jez³⁵, S. Jézéquel⁴, M.K. Jha^{19a}, H. Ji¹⁷³, W. Ji⁸¹, J. Jia¹⁴⁸, Y. Jiang^{32b}, M. Jimenez Belenguer⁴¹, S. Jin^{32a}, O. Jinnouchi¹⁵⁷, M.D. Joergensen³⁵, D. Joffe³⁹, M. Johansen^{146a,146b}, K.E. Johansson^{146a}, P. Johansson¹³⁹, S. Johnert⁴¹, K.A. Johns⁶, K. Jon-And^{146a,146b}, G. Jones¹⁷⁰, R.W.L. Jones⁷¹, T.J. Jones⁷³, C. Joram²⁹, P.M. Jorge^{124a}, K.D. Joshi⁸², J. Jovicevic¹⁴⁷, T. Jovin^{12b}, X. Ju¹⁷³, C.A. Jung⁴², R.M. Jungst²⁹, V. Juranek¹²⁵, P. Jussel⁶¹, A. Juste Rozas¹¹, S. Kabana¹⁶, M. Kaci¹⁶⁷, A. Kaczmarek³⁸, P. Kadlecik³⁵, M. Kado¹¹⁵, H. Kagan¹⁰⁹, M. Kagan⁵⁷, E. Kajomovitz¹⁵², S. Kalinin¹⁷⁵, L.V. Kalinovskaya⁶⁴, S. Kama³⁹, N. Kanaya¹⁵⁵, M. Kaneda²⁹, S. Kaneti²⁷, T. Kanno¹⁵⁷, V.A. Kantserov⁹⁶, J. Kanzaki⁶⁵, B. Kaplan¹⁷⁶, A. Kapliy³⁰, J. Kaplon²⁹, D. Kar⁵³, M. Karagounis²⁰, K. Karakostas⁹, M. Karnevskiy⁴¹, V. Kartvelishvili⁷¹, A.N. Karyukhin¹²⁸, L. Kashif¹⁷³, G. Kasieczka^{58b}, R.D. Kass¹⁰⁹, A. Kastanas¹³, M. Kataoka⁴, Y. Kataoka¹⁵⁵, E. Katsoufis⁹, J. Katzy⁴¹, V. Kaushik⁶, K. Kawagoe⁶⁹, T. Kawamoto¹⁵⁵, G. Kawamura⁸¹, M.S. Kayl¹⁰⁵, V.A. Kazanin¹⁰⁷, M.Y. Kazarinov⁶⁴, R. Keeler¹⁶⁹, R. Kehoe³⁹, M. Keil⁵⁴, G.D. Kekelidze⁶⁴, J.S. Keller¹³⁸, M. Kenyon⁵³, O. Kepka¹²⁵, N. Kerschen²⁹, B.P. Kerševan⁷⁴, S. Kersten¹⁷⁵, K. Kessoku¹⁵⁵, J. Keung¹⁵⁸, F. Khalil-zada¹⁰, H. Khandanyan¹⁶⁵, A. Khanov¹¹², D. Kharchenko⁶⁴, A. Khodinov⁹⁶, A. Khomich^{58a}, T.J. Khoo²⁷, G. Khorauli²⁰, A. Khoroshilov¹⁷⁵, V. Khovanskiy⁹⁵, E. Khramov⁶⁴, J. Khubua^{51b}, H. Kim^{146a,146b}, S.H. Kim¹⁶⁰, N. Kimura¹⁷¹, O. Kind¹⁵, B.T. King⁷³, M. King⁶⁶, R.S.B. King¹¹⁸, J. Kirk¹²⁹, A.E. Kiryunin⁹⁹, T. Kishimoto⁶⁶, D. Kisieleska³⁷, T. Kittelmann¹²³, E. Kladiva^{144b}, M. Klein⁷³, U. Klein⁷³, K. Kleinknecht⁸¹, M. Klemetti⁸⁵, A. Klier¹⁷², P. Klimek^{146a,146b}, A. Klimentov²⁴, R. Klingenberg⁴², J.A. Klinger⁸², E.B. Klinkby³⁵, T. Klioutchnikova²⁹, P.F. Klok¹⁰⁴, S. Klous¹⁰⁵, E.-E. Kluge^{58a}, T. Kluge⁷³, P. Kluit¹⁰⁵, S. Kluth⁹⁹, N.S. Knecht¹⁵⁸, E. Kneringer⁶¹, E.B.F.G. Knoops⁸³, A. Knue⁵⁴, B.R. Ko⁴⁴, T. Kobayashi¹⁵⁵, M. Kobel⁴³, M. Kocian¹⁴³, P. Kodys¹²⁶, K. Köneke²⁹, A.C. König¹⁰⁴, S. Koenig⁸¹, L. Köpke⁸¹, F. Koetsveld¹⁰⁴, P. Koevesarki²⁰, T. Koffas²⁸, E. Koffeman¹⁰⁵, L.A. Kogan¹¹⁸, S. Kohlmann¹⁷⁵, F. Kohn⁵⁴, Z. Kohout¹²⁷, T. Kohriki⁶⁵, T. Koi¹⁴³, G.M. Kolachev¹⁰⁷, H. Kolanoski¹⁵, V. Kolesnikov⁶⁴, I. Koletsou^{89a}, J. Koll⁸⁸, M. Kollefrath⁴⁸, A.A. Komar⁹⁴, Y. Komori¹⁵⁵, T. Kondo⁶⁵, T. Kono^{41,s}, A.I. Kononov⁴⁸, R. Konoplich^{108,t}, N. Konstantinidis⁷⁷, S. Koperny³⁷, K. Korcyl³⁸, K. Kordas¹⁵⁴, A. Korn¹¹⁸, A. Korol¹⁰⁷, I. Korolkov¹¹, E.V. Korolkova¹³⁹, V.A. Korotkov¹²⁸, O. Kortner⁹⁹, S. Kortner⁹⁹, V.V. Kostyukhin²⁰, S. Kotov⁹⁹, V.M. Kotov⁶⁴, A. Kotwal⁴⁴, C. Kourkoumelis⁸, V. Kouskoura¹⁵⁴, A. Koutsman^{159a}, R. Kowalewski¹⁶⁹, T.Z. Kowalski³⁷, W. Kozanecki¹³⁶, A.S. Kozhin¹²⁸, V. Kral¹²⁷, V.A. Kramarenko⁹⁷, G. Kramberger⁷⁴, M.W. Krasny⁷⁸, A. Krasznahorkay¹⁰⁸, J. Kraus⁸⁸, J.K. Kraus²⁰,

S. Kreiss¹⁰⁸, F. Krejci¹²⁷, J. Kretzschmar⁷³, N. Krieger⁵⁴, P. Krieger¹⁵⁸, K. Kroeninger⁵⁴,
 H. Kroha⁹⁹, J. Kroll¹²⁰, J. Kroseberg²⁰, J. Krstic^{12a}, U. Kruchonak⁶⁴, H. Krüger²⁰,
 T. Kruker¹⁶, N. Krumnack⁶³, Z.V. Krumshteyn⁶⁴, A. Kruth²⁰, T. Kubota⁸⁶, S. Kудay^{3a},
 S. Kuehn⁴⁸, A. Kugel^{58c}, T. Kuhl⁴¹, D. Kuhn⁶¹, V. Kukhtin⁶⁴, Y. Kulchitsky⁹⁰,
 S. Kuleshov^{31b}, C. Kummer⁹⁸, M. Kuna⁷⁸, J. Kunkle¹²⁰, A. Kupco¹²⁵, H. Kurashige⁶⁶,
 M. Kurata¹⁶⁰, Y.A. Kurochkin⁹⁰, V. Kus¹²⁵, E.S. Kuwertz¹⁴⁷, M. Kuze¹⁵⁷, J. Kvita¹⁴²,
 R. Kwee¹⁵, A. La Rosa⁴⁹, L. La Rotonda^{36a,36b}, L. Labarga⁸⁰, J. Labbe⁴, S. Lablak^{135a},
 C. Lacasta¹⁶⁷, F. Lacava^{132a,132b}, H. Lacker¹⁵, D. Lacour⁷⁸, V.R. Lacuesta¹⁶⁷,
 E. Ladygin⁶⁴, R. Lafaye⁴, B. Laforge⁷⁸, T. Lagouri⁸⁰, S. Lai⁴⁸, E. Laisne⁵⁵,
 M. Lamanna²⁹, L. Lambourne⁷⁷, C.L. Lampen⁶, W. Lampl⁶, E. Lancon¹³⁶,
 U. Landgraf⁴⁸, M.P.J. Landon⁷⁵, J.L. Lane⁸², V.S. Lang^{58a}, C. Lange⁴¹, A.J. Lankford¹⁶³,
 F. Lanni²⁴, K. Lantzsch¹⁷⁵, S. Laplace⁷⁸, C. Lapoire²⁰, J.F. Laporte¹³⁶, T. Lari^{89a},
 A. Larner¹¹⁸, M. Lassnig²⁹, P. Laurelli⁴⁷, V. Lavorini^{36a,36b}, W. Lavrijsen¹⁴, P. Laycock⁷³,
 O. Le Dortz⁷⁸, E. Le Guirriec⁸³, C. Le Maner¹⁵⁸, E. Le Menedeu¹¹, T. LeCompte⁵,
 F. Ledroit-Guillon⁵⁵, H. Lee¹⁰⁵, J.S.H. Lee¹¹⁶, S.C. Lee¹⁵¹, L. Lee¹⁷⁶, M. Lefebvre¹⁶⁹,
 M. Legendre¹³⁶, F. Legger⁹⁸, C. Leggett¹⁴, M. Lehmacher²⁰, G. Lehmann Miotto²⁹,
 X. Lei⁶, M.A.L. Leite^{23d}, R. Leitner¹²⁶, D. Lellouch¹⁷², B. Lemmer⁵⁴, V. Lendermann^{58a},
 K.J.C. Leney^{145b}, T. Lenz¹⁰⁵, G. Lenzen¹⁷⁵, B. Lenzi²⁹, K. Leonhardt⁴³, S. Leontsinis⁹,
 F. Lepold^{58a}, C. Leroy⁹³, J-R. Lessard¹⁶⁹, C.G. Lester²⁷, C.M. Lester¹²⁰, J. Levêque⁴,
 D. Levin⁸⁷, L.J. Levinson¹⁷², A. Lewis¹¹⁸, G.H. Lewis¹⁰⁸, A.M. Leyko²⁰, M. Leyton¹⁵,
 B. Li⁸³, H. Li^{173,u}, S. Li^{32b,v}, X. Li⁸⁷, Z. Liang^{118,w}, H. Liao³³, B. Liberti^{133a},
 P. Lichard²⁹, M. Lichtnecker⁹⁸, K. Lie¹⁶⁵, W. Liebig¹³, C. Limbach²⁰, A. Limosani⁸⁶,
 M. Limper⁶², S.C. Lin^{151,x}, F. Linde¹⁰⁵, J.T. Linnemann⁸⁸, E. Lipeles¹²⁰, A. Lipniacka¹³,
 T.M. Liss¹⁶⁵, D. Lissauer²⁴, A. Lister⁴⁹, A.M. Litke¹³⁷, C. Liu²⁸, D. Liu¹⁵¹, H. Liu⁸⁷,
 J.B. Liu⁸⁷, L. Liu⁸⁷, M. Liu^{32b}, Y. Liu^{32b}, M. Livan^{119a,119b}, S.S.A. Livermore¹¹⁸,
 A. Lleres⁵⁵, J. Llorente Merino⁸⁰, S.L. Lloyd⁷⁵, E. Lobodzinska⁴¹, P. Loch⁶,
 W.S. Lockman¹³⁷, T. Loddenkoetter²⁰, F.K. Loebinger⁸², A. Loginov¹⁷⁶, C.W. Loh¹⁶⁸,
 T. Lohse¹⁵, K. Lohwasser⁴⁸, M. Lokajicek¹²⁵, V.P. Lombardo⁴, R.E. Long⁷¹, L. Lopes^{124a},
 D. Lopez Mateos⁵⁷, J. Lorenz⁹⁸, N. Lorenzo Martinez¹¹⁵, M. Losada¹⁶², P. Loscutoff¹⁴,
 F. Lo Sterzo^{132a,132b}, M.J. Losty^{159a}, X. Lou⁴⁰, A. Lounis¹¹⁵, K.F. Loureiro¹⁶², J. Love²¹,
 P.A. Love⁷¹, A.J. Lowe^{143,e}, F. Lu^{32a}, H.J. Lubatti¹³⁸, C. Luci^{132a,132b}, A. Lucotte⁵⁵,
 A. Ludwig⁴³, D. Ludwig⁴¹, I. Ludwig⁴⁸, J. Ludwig⁴⁸, F. Luehring⁶⁰, G. Luijckx¹⁰⁵,
 W. Lukas⁶¹, D. Lumb⁴⁸, L. Luminari^{132a}, E. Lund¹¹⁷, B. Lund-Jensen¹⁴⁷, B. Lundberg⁷⁹,
 J. Lundberg^{146a,146b}, O. Lundberg^{146a,146b}, J. Lundquist³⁵, M. Lungwitz⁸¹, D. Lynn²⁴,
 E. Lytken⁷⁹, H. Ma²⁴, L.L. Ma¹⁷³, G. Maccarrone⁴⁷, A. Macchiolo⁹⁹, B. Maček⁷⁴,
 J. Machado Miguens^{124a}, R. Mackeprang³⁵, R.J. Madaras¹⁴, W.F. Mader⁴³,
 R. Maenner^{58c}, T. Maeno²⁴, P. Mättig¹⁷⁵, S. Mättig⁴¹, L. Magnoni²⁹, E. Magradze⁵⁴,
 K. Mahboubi⁴⁸, S. Mahmoud⁷³, G. Mahout¹⁷, C. Maiani¹³⁶, C. Maidantchik^{23a},
 A. Maio^{124a,b}, S. Majewski²⁴, Y. Makida⁶⁵, N. Makovec¹¹⁵, P. Mal¹³⁶, B. Malaescu²⁹,
 Pa. Malecki³⁸, P. Malecki³⁸, V.P. Maleev¹²¹, F. Malek⁵⁵, U. Mallik⁶², D. Malon⁵,
 C. Malone¹⁴³, S. Maltezos⁹, V. Malyshev¹⁰⁷, S. Malyukov²⁹, R. Mameghani⁹⁸,
 J. Mamuzic^{12b}, A. Manabe⁶⁵, L. Mandelli^{89a}, I. Mandić⁷⁴, R. Mandrysch¹⁵,
 J. Maneira^{124a}, P.S. Mangeard⁸⁸, L. Manhaes de Andrade Filho^{23a}, A. Mann⁵⁴,

P.M. Manning¹³⁷, A. Manousakis-Katsikakis⁸, B. Mansoulie¹³⁶, A. Mapelli²⁹,
 L. Mapelli²⁹, L. March⁸⁰, J.F. Marchand²⁸, F. Marchese^{133a,133b}, G. Marchiori⁷⁸,
 M. Marcisovsky¹²⁵, C.P. Marino¹⁶⁹, F. Marroquim^{23a}, Z. Marshall²⁹, F.K. Martens¹⁵⁸,
 L.F. Marti¹⁶, S. Marti-Garcia¹⁶⁷, B. Martin²⁹, B. Martin⁸⁸, J.P. Martin⁹³, T.A. Martin¹⁷,
 V.J. Martin⁴⁵, B. Martin dit Latour⁴⁹, S. Martin-Haugh¹⁴⁹, M. Martinez¹¹,
 V. Martinez Outschoorn⁵⁷, A.C. Martyniuk¹⁶⁹, M. Marx⁸², F. Marzano^{132a}, A. Marzin¹¹¹,
 L. Masetti⁸¹, T. Mashimo¹⁵⁵, R. Mashinistov⁹⁴, J. Masik⁸², A.L. Maslennikov¹⁰⁷,
 I. Massa^{19a,19b}, G. Massaro¹⁰⁵, N. Massol⁴, A. Mastroberardino^{36a,36b}, T. Masubuchi¹⁵⁵,
 P. Matricon¹¹⁵, H. Matsunaga¹⁵⁵, T. Matsushita⁶⁶, C. Mattravers^{118,c}, J. Maurer⁸³,
 S.J. Maxfield⁷³, A. Mayne¹³⁹, R. Mazini¹⁵¹, M. Mazur²⁰, L. Mazzaferro^{133a,133b},
 M. Mazzanti^{89a}, S.P. Mc Kee⁸⁷, A. McCarn¹⁶⁵, R.L. McCarthy¹⁴⁸, T.G. McCarthy²⁸,
 N.A. McCubbin¹²⁹, K.W. McFarlane⁵⁶, J.A. Mcfayden¹³⁹, H. McGlone⁵³,
 G. Mchedlidze^{51b}, T. McLaughlan¹⁷, S.J. McMahon¹²⁹, R.A. McPherson^{169,k}, A. Meade⁸⁴,
 J. Mechnich¹⁰⁵, M. Mechtel¹⁷⁵, M. Medinnis⁴¹, R. Meera-Lebbai¹¹¹, T. Meguro¹¹⁶,
 R. Mehdiyev⁹³, S. Mehlhase³⁵, A. Mehta⁷³, K. Meier^{58a}, B. Meirose⁷⁹, C. Melachrinou³⁰,
 B.R. Mellado Garcia¹⁷³, F. Meloni^{89a,89b}, L. Mendoza Navas¹⁶², Z. Meng^{151,u},
 A. Mengarelli^{19a,19b}, S. Menke⁹⁹, E. Meoni¹⁶¹, K.M. Mercurio⁵⁷, P. Mermoud⁴⁹,
 L. Merola^{102a,102b}, C. Meroni^{89a}, F.S. Merritt³⁰, H. Merritt¹⁰⁹, A. Messina^{29,y},
 J. Metcalfe¹⁰³, A.S. Mete¹⁶³, C. Meyer⁸¹, C. Meyer³⁰, J-P. Meyer¹³⁶, J. Meyer¹⁷⁴,
 J. Meyer⁵⁴, T.C. Meyer²⁹, W.T. Meyer⁶³, J. Miao^{32d}, S. Michal²⁹, L. Micu^{25a},
 R.P. Middleton¹²⁹, S. Migas⁷³, L. Mijović¹³⁶, G. Mikenberg¹⁷², M. Mikesikova¹²⁵,
 M. Mikuš⁷⁴, D.W. Miller³⁰, R.J. Miller⁸⁸, W.J. Mills¹⁶⁸, C. Mills⁵⁷, A. Milov¹⁷²,
 D.A. Milstead^{146a,146b}, D. Milstein¹⁷², A.A. Minaenko¹²⁸, M. Miñano Moya¹⁶⁷,
 I.A. Minashvili⁶⁴, A.I. Mincer¹⁰⁸, B. Mindur³⁷, M. Mineev⁶⁴, Y. Ming¹⁷³, L.M. Mir¹¹,
 G. Mirabelli^{132a}, J. Mitrevski¹³⁷, V.A. Mitsou¹⁶⁷, S. Mitsui⁶⁵, P.S. Miyagawa¹³⁹,
 J.U. Mjörnmark⁷⁹, T. Moa^{146a,146b}, V. Moeller²⁷, K. Mönig⁴¹, N. Möser²⁰,
 S. Mohapatra¹⁴⁸, W. Mohr⁴⁸, R. Moles-Valls¹⁶⁷, J. Monk⁷⁷, E. Monnier⁸³,
 J. Montejó Berlingen¹¹, S. Montesano^{89a,89b}, F. Monticelli⁷⁰, S. Monzani^{19a,19b},
 R.W. Moore², G.F. Moorhead⁸⁶, C. Mora Herrera⁴⁹, A. Moraes⁵³, N. Morange¹³⁶,
 J. Morel⁵⁴, G. Morello^{36a,36b}, D. Moreno⁸¹, M. Moreno Llácer¹⁶⁷, P. Morettini^{50a},
 M. Morgenstern⁴³, M. Morii⁵⁷, A.K. Morley²⁹, G. Mornacchi²⁹, J.D. Morris⁷⁵,
 L. Morvaj¹⁰¹, H.G. Moser⁹⁹, M. Mosidze^{51b}, J. Moss¹⁰⁹, R. Mount¹⁴³, E. Mountricha^{9,z},
 S.V. Mouraviev⁹⁴, E.J.W. Moyse⁸⁴, F. Mueller^{58a}, J. Mueller¹²³, K. Mueller²⁰,
 T.A. Müller⁹⁸, T. Mueller⁸¹, D. Muenstermann²⁹, Y. Munwes¹⁵³, W.J. Murray¹²⁹,
 I. Mussche¹⁰⁵, E. Musto^{102a,102b}, A.G. Myagkov¹²⁸, M. Myska¹²⁵, J. Nadal¹¹, K. Nagai¹⁶⁰,
 K. Nagano⁶⁵, A. Nagarkar¹⁰⁹, Y. Nagasaka⁵⁹, M. Nagel⁹⁹, A.M. Nairz²⁹, Y. Nakahama²⁹,
 K. Nakamura¹⁵⁵, T. Nakamura¹⁵⁵, I. Nakano¹¹⁰, G. Nanava²⁰, A. Napier¹⁶¹,
 R. Narayan^{58b}, M. Nash^{77,c}, T. Nattermann²⁰, T. Naumann⁴¹, G. Navarro¹⁶²,
 H.A. Neal⁸⁷, P.Yu. Nechaeva⁹⁴, T.J. Neep⁸², A. Negri^{119a,119b}, G. Negri²⁹,
 S. Nektarijevic⁴⁹, A. Nelson¹⁶³, T.K. Nelson¹⁴³, S. Nemecek¹²⁵, P. Nemethy¹⁰⁸,
 A.A. Nepomuceno^{23a}, M. Nessi^{29,aa}, M.S. Neubauer¹⁶⁵, A. Neusiedl⁸¹, R.M. Neves¹⁰⁸,
 P. Nevski²⁴, P.R. Newman¹⁷, V. Nguyen Thi Hong¹³⁶, R.B. Nickerson¹¹⁸,
 R. Nicolaidou¹³⁶, B. Niquevert²⁹, F. Niedercorn¹¹⁵, J. Nielsen¹³⁷, N. Nikiforou³⁴,

A. Nikiforov¹⁵, V. Nikolaenko¹²⁸, I. Nikolic-Audit⁷⁸, K. Nikolics⁴⁹, K. Nikolopoulos²⁴,
 H. Nilsen⁴⁸, P. Nilsson⁷, Y. Ninomiya¹⁵⁵, A. Nisati^{132a}, R. Nisius⁹⁹, T. Nobe¹⁵⁷,
 L. Nodulman⁵, M. Nomachi¹¹⁶, I. Nomidis¹⁵⁴, M. Nordberg²⁹, P.R. Norton¹²⁹,
 J. Novakova¹²⁶, M. Nozaki⁶⁵, L. Nozka¹¹³, I.M. Nugent^{159a}, A.-E. Nuncio-Quiroz²⁰,
 G. Nunes Hanninger⁸⁶, T. Nunnemann⁹⁸, E. Nurse⁷⁷, B.J. O'Brien⁴⁵, S.W. O'Neale^{17,*},
 D.C. O'Neil¹⁴², V. O'Shea⁵³, L.B. Oakes⁹⁸, F.G. Oakham^{28,d}, H. Oberlack⁹⁹, J. Ocariz⁷⁸,
 A. Ochi⁶⁶, S. Oda⁶⁹, S. Odaka⁶⁵, J. Odier⁸³, H. Ogren⁶⁰, A. Oh⁸², S.H. Oh⁴⁴,
 C.C. Ohm^{146a,146b}, T. Ohshima¹⁰¹, H. Okawa¹⁶³, Y. Okumura³⁰, T. Okuyama¹⁵⁵,
 A. Olariu^{25a}, A.G. Olchevski⁶⁴, S.A. Olivares Pino^{31a}, M. Oliveira^{124a,h},
 D. Oliveira Damazio²⁴, E. Oliver Garcia¹⁶⁷, D. Olivito¹²⁰, A. Olszewski³⁸, J. Olszowska³⁸,
 A. Onofre^{124a,ab}, P.U.E. Onyisi³⁰, C.J. Oram^{159a}, M.J. Oreglia³⁰, Y. Oren¹⁵³,
 D. Orestano^{134a,134b}, N. Orlando^{72a,72b}, I. Orlov¹⁰⁷, C. Oropeza Barrera⁵³, R.S. Orr¹⁵⁸,
 B. Osculati^{50a,50b}, R. Ospanov¹²⁰, C. Osuna¹¹, G. Otero y Garzon²⁶, J.P. Ottersbach¹⁰⁵,
 M. Ouchrif^{135d}, E.A. Ouellette¹⁶⁹, F. Ould-Saada¹¹⁷, A. Ouraou¹³⁶, Q. Ouyang^{32a},
 A. Ovcharova¹⁴, M. Owen⁸², S. Owen¹³⁹, V.E. Ozcan^{18a}, N. Ozturk⁷, A. Pacheco Pages¹¹,
 C. Padilla Aranda¹¹, S. Pagan Griso¹⁴, E. Paganis¹³⁹, F. Paige²⁴, P. Pais⁸⁴, K. Pajchel¹¹⁷,
 G. Palacino^{159b}, C.P. Paleari⁶, S. Palestini²⁹, D. Pallin³³, A. Palma^{124a}, J.D. Palmer¹⁷,
 Y.B. Pan¹⁷³, E. Panagiotopoulou⁹, P. Pani¹⁰⁵, N. Panikashvili⁸⁷, S. Panitkin²⁴,
 D. Pantea^{25a}, A. Papadelis^{146a}, Th.D. Papadopoulou⁹, A. Paramonov⁵,
 D. Paredes Hernandez³³, W. Park^{24,ac}, M.A. Parker²⁷, F. Parodi^{50a,50b}, J.A. Parsons³⁴,
 U. Parzefall⁴⁸, S. Pashapour⁵⁴, E. Pasqualucci^{132a}, S. Passaggio^{50a}, A. Passeri^{134a},
 F. Pastore^{134a,134b}, Fr. Pastore⁷⁶, G. Pásztor^{49,ad}, S. Pataraia¹⁷⁵, N. Patel¹⁵⁰,
 J.R. Pater⁸², S. Patricelli^{102a,102b}, T. Pauly²⁹, M. Pecsny^{144a}, M.I. Pedraza Morales¹⁷³,
 S.V. Peleganchuk¹⁰⁷, D. Pelikan¹⁶⁶, H. Peng^{32b}, B. Penning³⁰, A. Penson³⁴, J. Penwell⁶⁰,
 M. Perantoni^{23a}, K. Perez^{34,ae}, T. Perez Cavalcanti⁴¹, E. Perez Codina^{159a}, M.T. Pérez
 García-Estañ¹⁶⁷, V. Perez Reale³⁴, L. Perini^{89a,89b}, H. Pernegger²⁹, R. Perrino^{72a},
 P. Perrodo⁴, V.D. Peshekhonov⁶⁴, K. Peters²⁹, B.A. Petersen²⁹, J. Petersen²⁹,
 T.C. Petersen³⁵, E. Petit⁴, A. Petridis¹⁵⁴, C. Petridou¹⁵⁴, E. Petrolo^{132a},
 F. Petrucci^{134a,134b}, D. Petschull⁴¹, M. Petteni¹⁴², R. Pezoa^{31b}, A. Phan⁸⁶,
 P.W. Phillips¹²⁹, G. Piacquadio²⁹, A. Picazio⁴⁹, E. Piccaro⁷⁵, M. Piccinini^{19a,19b},
 S.M. Piec⁴¹, R. Piegai²⁶, D.T. Pignotti¹⁰⁹, J.E. Pilcher³⁰, A.D. Pilkington⁸²,
 J. Pina^{124a,b}, M. Pinamonti^{164a,164c}, A. Pinder¹¹⁸, J.L. Pinfold², B. Pinto^{124a},
 C. Pizio^{89a,89b}, M. Plamondon¹⁶⁹, M.-A. Pleier²⁴, E. Plotnikova⁶⁴, A. Poblaguev²⁴,
 S. Poddar^{58a}, F. Podlyski³³, L. Poggioli¹¹⁵, T. Poghosyan²⁰, M. Pohl⁴⁹, G. Polesello^{119a},
 A. Policicchio^{36a,36b}, A. Polini^{19a}, J. Poll⁷⁵, V. Polychronakos²⁴, D. Pomeroy²²,
 K. Pommès²⁹, L. Pontecorvo^{132a}, B.G. Pope⁸⁸, G.A. Popeneciu^{25a}, D.S. Popovic^{12a},
 A. Poppleton²⁹, X. Portell Bueso²⁹, G.E. Pospelov⁹⁹, S. Pospisil¹²⁷, I.N. Potrap⁹⁹,
 C.J. Potter¹⁴⁹, C.T. Potter¹¹⁴, G. Poulard²⁹, J. Poveda⁶⁰, V. Pozdnyakov⁶⁴, R. Prabhu⁷⁷,
 P. Pralavorio⁸³, A. Pranko¹⁴, S. Prasad²⁹, R. Pravahan²⁴, S. Prell⁶³, K. Pretzl¹⁶,
 D. Price⁶⁰, J. Price⁷³, L.E. Price⁵, D. Prieur¹²³, M. Primavera^{72a}, K. Prokofiev¹⁰⁸,
 F. Prokoshin^{31b}, S. Protopopescu²⁴, J. Proudfoot⁵, X. Prudent⁴³, M. Przybycien³⁷,
 H. Przysieznik⁴, S. Psoroulas²⁰, E. Ptacek¹¹⁴, E. Pueschel⁸⁴, J. Purdham⁸⁷,
 M. Purohit^{24,ac}, P. Puzo¹¹⁵, Y. Pylypchenko⁶², J. Qian⁸⁷, A. Quadt⁵⁴, D.R. Quarrie¹⁴,

W.B. Quayle¹⁷³, F. Quinonez^{31a}, M. Raas¹⁰⁴, V. Radescu⁴¹, P. Radloff¹¹⁴, T. Rador^{18a},
 F. Ragusa^{89a,89b}, G. Rahal¹⁷⁸, A.M. Rahimi¹⁰⁹, D. Rahm²⁴, S. Rajagopalan²⁴,
 M. Rammensee⁴⁸, M. Rammes¹⁴¹, A.S. Randle-Conde³⁹, K. Randrianarivony²⁸,
 F. Rauscher⁹⁸, T.C. Rave⁴⁸, M. Raymond²⁹, A.L. Read¹¹⁷, D.M. Rebutti^{119a,119b},
 A. Redelbach¹⁷⁴, G. Redlinger²⁴, R. Reece¹²⁰, K. Reeves⁴⁰, E. Reinherz-Aronis¹⁵³,
 A. Reinsch¹¹⁴, I. Reisinger⁴², C. Rembser²⁹, Z.L. Ren¹⁵¹, A. Renaud¹¹⁵, M. Rescigno^{132a},
 S. Resconi^{89a}, B. Resende¹³⁶, P. Reznicek⁹⁸, R. Rezvani¹⁵⁸, R. Richter⁹⁹,
 E. Richter-Was^{4,af}, M. Ridel⁷⁸, M. Rijpstra¹⁰⁵, M. Rijssenbeek¹⁴⁸, A. Rimoldi^{119a,119b},
 L. Rinaldi^{19a}, R.R. Rios³⁹, I. Riu¹¹, G. Rivoltella^{89a,89b}, F. Rizatdinova¹¹², E. Rizvi⁷⁵,
 S.H. Robertson^{85,k}, A. Robichaud-Veronneau¹¹⁸, D. Robinson²⁷, J.E.M. Robinson⁷⁷,
 A. Robson⁵³, J.G. Rocha de Lima¹⁰⁶, C. Roda^{122a,122b}, D. Roda Dos Santos²⁹, A. Roe⁵⁴,
 S. Roe²⁹, O. Røhne¹¹⁷, S. Rolli¹⁶¹, A. Romaniouk⁹⁶, M. Romano^{19a,19b}, G. Romeo²⁶,
 E. Romero Adam¹⁶⁷, L. Roos⁷⁸, E. Ros¹⁶⁷, S. Rosati^{132a}, K. Rosbach⁴⁹, A. Rose¹⁴⁹,
 M. Rose⁷⁶, G.A. Rosenbaum¹⁵⁸, E.I. Rosenberg⁶³, P.L. Rosendahl¹³, O. Rosenthal¹⁴¹,
 L. Rosselet⁴⁹, V. Rossetti¹¹, E. Rossi^{132a,132b}, L.P. Rossi^{50a}, M. Rotaru^{25a}, I. Roth¹⁷²,
 J. Rothberg¹³⁸, D. Rousseau¹¹⁵, C.R. Royon¹³⁶, A. Rozanov⁸³, Y. Rozen¹⁵²,
 X. Ruan^{32a,ag}, F. Rubbo¹¹, I. Rubinskiy⁴¹, B. Ruckert⁹⁸, N. Ruckstuhl¹⁰⁵, V.I. Rud⁹⁷,
 C. Rudolph⁴³, G. Rudolph⁶¹, F. Rühr⁶, A. Ruiz-Martinez⁶³, L. Rumyantsev⁶⁴,
 Z. Rurikova⁴⁸, N.A. Rusakovich⁶⁴, J.P. Rutherford⁶, C. Ruwiedel¹⁴, P. Ruzicka¹²⁵,
 Y.F. Ryabov¹²¹, P. Ryan⁸⁸, M. Rybar¹²⁶, G. Rybkin¹¹⁵, N.C. Ryder¹¹⁸, A.F. Saavedra¹⁵⁰,
 I. Sadeh¹⁵³, H.F.-W. Sadrozinski¹³⁷, R. Sadykov⁶⁴, F. Safai Tehrani^{132a}, H. Sakamoto¹⁵⁵,
 G. Salamanna⁷⁵, A. Salamon^{133a}, M. Saleem¹¹¹, D. Salek²⁹, D. Salihagic⁹⁹,
 A. Salnikov¹⁴³, J. Salt¹⁶⁷, B.M. Salvachua Ferrando⁵, D. Salvatore^{36a,36b}, F. Salvatore¹⁴⁹,
 A. Salvucci¹⁰⁴, A. Salzburger²⁹, D. Sampsonidis¹⁵⁴, B.H. Samset¹¹⁷, A. Sanchez^{102a,102b},
 V. Sanchez Martinez¹⁶⁷, H. Sandaker¹³, H.G. Sander⁸¹, M.P. Sanders⁹⁸, M. Sandhoff¹⁷⁵,
 T. Sandoval²⁷, C. Sandoval¹⁶², R. Sandstroem⁹⁹, D.P.C. Sankey¹²⁹, A. Sansoni⁴⁷,
 C. Santamarina Rios⁸⁵, C. Santoni³³, R. Santonico^{133a,133b}, H. Santos^{124a},
 J.G. Saraiva^{124a}, T. Sarangi¹⁷³, E. Sarkisyan-Grinbaum⁷, F. Sarri^{122a,122b},
 G. Sartisohn¹⁷⁵, O. Sasaki⁶⁵, N. Sasao⁶⁷, I. Satsounkevitch⁹⁰, G. Sauvage⁴, E. Sauvan⁴,
 J.B. Sauvan¹¹⁵, P. Savard^{158,d}, V. Savinov¹²³, D.O. Savu²⁹, L. Sawyer^{24,m}, D.H. Saxon⁵³,
 J. Saxon¹²⁰, C. Sbarra^{19a}, A. Sbrizzi^{19a,19b}, O. Scallan⁹³, D.A. Scannicchio¹⁶³,
 M. Scarcella¹⁵⁰, J. Schaarschmidt¹¹⁵, P. Schacht⁹⁹, D. Schaefer¹²⁰, U. Schäfer⁸¹,
 S. Schaepe²⁰, S. Schaetzel^{58b}, A.C. Schaffer¹¹⁵, D. Schaile⁹⁸, R.D. Schamberger¹⁴⁸,
 A.G. Schamov¹⁰⁷, V. Scharf^{58a}, V.A. Schegelsky¹²¹, D. Scheirich⁸⁷, M. Schernau¹⁶³,
 M.I. Scherzer³⁴, C. Schiavi^{50a,50b}, J. Schieck⁹⁸, M. Schioppa^{36a,36b}, S. Schlenker²⁹,
 E. Schmidt⁴⁸, K. Schmieden²⁰, C. Schmitt⁸¹, S. Schmitt^{58b}, M. Schmitz²⁰, B. Schneider¹⁶,
 U. Schnoor⁴³, A. Schoening^{58b}, A.L.S. Schorlemmer⁵⁴, M. Schott²⁹, D. Schouten^{159a},
 J. Schovancova¹²⁵, M. Schram⁸⁵, C. Schroeder⁸¹, N. Schroer^{58c}, M.J. Schultens²⁰,
 J. Schultes¹⁷⁵, H.-C. Schultz-Coulon^{58a}, H. Schulz¹⁵, M. Schumacher⁴⁸, B.A. Schumm¹³⁷,
 Ph. Schune¹³⁶, C. Schwanenberger⁸², A. Schwartzman¹⁴³, Ph. Schwemling⁷⁸,
 R. Schwienhorst⁸⁸, R. Schwierz⁴³, J. Schwindling¹³⁶, T. Schwindt²⁰, M. Schwoerer⁴,
 G. Sciolla²², W.G. Scott¹²⁹, J. Searcy¹¹⁴, G. Sedov⁴¹, E. Sedykh¹²¹, S.C. Seidel¹⁰³,
 A. Seiden¹³⁷, F. Seifert⁴³, J.M. Seixas^{23a}, G. Sekhniaidze^{102a}, S.J. Sekula³⁹,

K.E. Selbach⁴⁵, D.M. Seliverstov¹²¹, B. Sellden^{146a}, G. Sellers⁷³, M. Seman^{144b},
 N. Semprini-Cesari^{19a,19b}, C. Serfon⁹⁸, L. Serin¹¹⁵, L. Serkin⁵⁴, R. Seuster⁹⁹,
 H. Severini¹¹¹, A. Sfyrla²⁹, E. Shabalina⁵⁴, M. Shamim¹¹⁴, L.Y. Shan^{32a}, J.T. Shank²¹,
 Q.T. Shao⁸⁶, M. Shapiro¹⁴, P.B. Shatalov⁹⁵, K. Shaw^{164a,164c}, D. Sherman¹⁷⁶,
 P. Sherwood⁷⁷, A. Shibata¹⁰⁸, S. Shimizu²⁹, M. Shimojima¹⁰⁰, T. Shin⁵⁶, M. Shiyakova⁶⁴,
 A. Shmeleva⁹⁴, M.J. Shochet³⁰, D. Short¹¹⁸, S. Shrestha⁶³, E. Shulga⁹⁶, M.A. Shupe⁶,
 P. Sicho¹²⁵, A. Sidoti^{132a}, F. Siegert⁴⁸, Dj. Sijacki^{12a}, O. Silbert¹⁷², J. Silva^{124a},
 Y. Silver¹⁵³, D. Silverstein¹⁴³, S.B. Silverstein^{146a}, V. Simak¹²⁷, O. Simard¹³⁶,
 Lj. Simic^{12a}, S. Simion¹¹⁵, E. Simioni⁸¹, B. Simmons⁷⁷, R. Simoniello^{89a,89b},
 M. Simonyan³⁵, P. Sinervo¹⁵⁸, N.B. Sinev¹¹⁴, V. Sipica¹⁴¹, G. Siragusa¹⁷⁴, A. Sircar²⁴,
 A.N. Sisakyan⁶⁴, S.Yu. Sivoklokov⁹⁷, J. Sjölin^{146a,146b}, T.B. Sjursen¹³, L.A. Skinnari¹⁴,
 H.P. Skottowe⁵⁷, K. Skovpen¹⁰⁷, P. Skubic¹¹¹, M. Slater¹⁷, T. Slavicek¹²⁷, K. Sliwa¹⁶¹,
 V. Smakhtin¹⁷², B.H. Smart⁴⁵, S.Yu. Smirnov⁹⁶, Y. Smirnov⁹⁶, L.N. Smirnova⁹⁷,
 O. Smirnova⁷⁹, B.C. Smith⁵⁷, D. Smith¹⁴³, K.M. Smith⁵³, M. Smizanska⁷¹, K. Smolek¹²⁷,
 A.A. Snesarev⁹⁴, S.W. Snow⁸², J. Snow¹¹¹, S. Snyder²⁴, R. Sobie^{169,k}, J. Sodomka¹²⁷,
 A. Soffer¹⁵³, C.A. Solans¹⁶⁷, M. Solar¹²⁷, J. Solc¹²⁷, E.Yu. Soldatov⁹⁶, U. Soldevila¹⁶⁷,
 E. Solfaroli Camillocci^{132a,132b}, A.A. Solodkov¹²⁸, O.V. Solovyanov¹²⁸, N. Soni²,
 V. Sopko¹²⁷, B. Sopko¹²⁷, M. Sosebee⁷, R. Soualah^{164a,164c}, A. Soukharev¹⁰⁷,
 S. Spagnolo^{72a,72b}, F. Spanò⁷⁶, R. Spighi^{19a}, G. Spigo²⁹, F. Spila^{132a,132b}, R. Spiwoks²⁹,
 M. Spousta¹²⁶, T. Spreitzer¹⁵⁸, B. Spurlock⁷, R.D. St. Denis⁵³, J. Stahlman¹²⁰,
 R. Stamen^{58a}, E. Stanecka³⁸, R.W. Stanek⁵, C. Stanescu^{134a}, M. Stanescu-Bellu⁴¹,
 S. Stapnes¹¹⁷, E.A. Starchenko¹²⁸, J. Stark⁵⁵, P. Staroba¹²⁵, P. Starovoitov⁴¹,
 R. Staszewski³⁸, A. Staude⁹⁸, P. Stavina^{144a}, G. Steele⁵³, P. Steinbach⁴³, P. Steinberg²⁴,
 I. Stekl¹²⁷, B. Stelzer¹⁴², H.J. Stelzer⁸⁸, O. Stelzer-Chilton^{159a}, H. Stenzel⁵², S. Stern⁹⁹,
 G.A. Stewart²⁹, J.A. Stillings²⁰, M.C. Stockton⁸⁵, K. Stoerig⁴⁸, G. Stoicea^{25a},
 S. Stonjek⁹⁹, P. Strachota¹²⁶, A.R. Stradling⁷, A. Straessner⁴³, J. Strandberg¹⁴⁷,
 S. Strandberg^{146a,146b}, A. Strandlie¹¹⁷, M. Strang¹⁰⁹, E. Strauss¹⁴³, M. Strauss¹¹¹,
 P. Strizenec^{144b}, R. Ströhmer¹⁷⁴, D.M. Strom¹¹⁴, J.A. Strong^{76,*}, R. Stroynowski³⁹,
 J. Strube¹²⁹, B. Stugu¹³, I. Stumer^{24,*}, J. Stupak¹⁴⁸, P. Sturm¹⁷⁵, N.A. Styles⁴¹,
 D.A. Soh^{151,w}, D. Su¹⁴³, H.S. Subramania², A. Succurro¹¹, Y. Sugaya¹¹⁶, C. Suhr¹⁰⁶,
 M. Suk¹²⁶, V.V. Sulin⁹⁴, S. Sultansoy^{3d}, T. Sumida⁶⁷, X. Sun⁵⁵, J.E. Sundermann⁴⁸,
 K. Suruliz¹³⁹, G. Susinno^{36a,36b}, M.R. Sutton¹⁴⁹, Y. Suzuki⁶⁵, Y. Suzuki⁶⁶, M. Svatos¹²⁵,
 S. Swedish¹⁶⁸, I. Sykora^{144a}, T. Sykora¹²⁶, J. Sánchez¹⁶⁷, D. Ta¹⁰⁵, K. Tackmann⁴¹,
 A. Taffard¹⁶³, R. Tahirout^{159a}, N. Taiblum¹⁵³, Y. Takahashi¹⁰¹, H. Takai²⁴,
 R. Takashima⁶⁸, H. Takeda⁶⁶, T. Takeshita¹⁴⁰, Y. Takubo⁶⁵, M. Talby⁸³,
 A. Talyshev^{107,f}, M.C. Tamsett²⁴, J. Tanaka¹⁵⁵, R. Tanaka¹¹⁵, S. Tanaka¹³¹, S. Tanaka⁶⁵,
 A.J. Tanasijczuk¹⁴², K. Tani⁶⁶, N. Tannoury⁸³, S. Tapprogge⁸¹, D. Tardif¹⁵⁸, S. Tarem¹⁵²,
 F. Tarrade²⁸, G.F. Tartarelli^{89a}, P. Tas¹²⁶, M. Tasevsky¹²⁵, E. Tassi^{36a,36b},
 M. Tatarkhanov¹⁴, Y. Tayalati^{135d}, C. Taylor⁷⁷, F.E. Taylor⁹², G.N. Taylor⁸⁶,
 W. Taylor^{159b}, M. Teinturier¹¹⁵, M. Teixeira Dias Castanheira⁷⁵, P. Teixeira-Dias⁷⁶,
 K.K. Temming⁴⁸, H. Ten Kate²⁹, P.K. Teng¹⁵¹, S. Terada⁶⁵, K. Terashi¹⁵⁵, J. Terron⁸⁰,
 M. Testa⁴⁷, R.J. Teuscher^{158,k}, J. Therhaag²⁰, T. Theveneaux-Pelzer⁷⁸, S. Thoma⁴⁸,
 J.P. Thomas¹⁷, E.N. Thompson³⁴, P.D. Thompson¹⁷, P.D. Thompson¹⁵⁸,

A.S. Thompson⁵³, L.A. Thomsen³⁵, E. Thomson¹²⁰, M. Thomson²⁷, R.P. Thun⁸⁷,
 F. Tian³⁴, M.J. Tibbetts¹⁴, T. Tic¹²⁵, V.O. Tikhomirov⁹⁴, Y.A. Tikhonov^{107,f},
 S. Timoshenko⁹⁶, P. Tipton¹⁷⁶, F.J. Tique Aires Viegas²⁹, S. Tisserant⁸³, T. Todorov⁴,
 S. Todorova-Nova¹⁶¹, B. Toggerson¹⁶³, J. Tojo⁶⁹, S. Tokár^{144a}, K. Tokushuku⁶⁵,
 K. Tollefson⁸⁸, M. Tomoto¹⁰¹, L. Tompkins³⁰, K. Toms¹⁰³, A. Tonoyan¹³, C. Topfel¹⁶,
 N.D. Topilin⁶⁴, I. Torchiani²⁹, E. Torrence¹¹⁴, H. Torres⁷⁸, E. Torró Pastor¹⁶⁷,
 J. Toth^{83,ad}, F. Touchard⁸³, D.R. Tovey¹³⁹, T. Trefzger¹⁷⁴, L. Tremblet²⁹, A. Tricoli²⁹,
 I.M. Trigger^{159a}, S. Trincas-Duvoid⁷⁸, M.F. Tripiana⁷⁰, W. Trischuk¹⁵⁸, B. Trocmé⁵⁵,
 C. Troncon^{89a}, M. Trottier-McDonald¹⁴², M. Trzebinski³⁸, A. Trzupek³⁸,
 C. Tsarouchas²⁹, J.C.-L. Tseng¹¹⁸, M. Tsiakiris¹⁰⁵, P.V. Tsiarehka⁹⁰, D. Tsionou^{4,ah},
 G. Tsipolitis⁹, S. Tsiskaridze¹¹, V. Tsiskaridze⁴⁸, E.G. Tskhadadze^{51a}, I.I. Tsukerman⁹⁵,
 V. Tsulaia¹⁴, J.-W. Tsung²⁰, S. Tsuno⁶⁵, D. Tsybychev¹⁴⁸, A. Tua¹³⁹, A. Tudorache^{25a},
 V. Tudorache^{25a}, J.M. Tuggle³⁰, M. Turala³⁸, D. Turecek¹²⁷, I. Turk Cakir^{3e},
 E. Turley¹⁰⁵, R. Turra^{89a,89b}, P.M. Tuts³⁴, A. Tykhonov⁷⁴, M. Tylmad^{146a,146b},
 M. Tyndel¹²⁹, G. Tzanakos⁸, K. Uchida²⁰, I. Ueda¹⁵⁵, R. Ueno²⁸, M. Ugland¹³,
 M. Uhlenbrock²⁰, M. Uhrmacher⁵⁴, F. Ukegawa¹⁶⁰, G. Unal²⁹, A. Undrus²⁴, G. Unel¹⁶³,
 Y. Unno⁶⁵, D. Urbaniec³⁴, G. Usai⁷, M. Uslenghi^{119a,119b}, L. Vacavant⁸³, V. Vacek¹²⁷,
 B. Vachon⁸⁵, S. Vahsen¹⁴, J. Valenta¹²⁵, P. Valente^{132a}, S. Valentinetti^{19a,19b},
 A. Valero¹⁶⁷, S. Valkar¹²⁶, E. Valladolid Gallego¹⁶⁷, S. Vallecorsa¹⁵², J.A. Valls Ferrer¹⁶⁷,
 H. van der Graaf¹⁰⁵, E. van der Kraaij¹⁰⁵, R. Van Der Leeuw¹⁰⁵, E. van der Poel¹⁰⁵,
 D. van der Ster²⁹, N. van Eldik²⁹, P. van Gemmeren⁵, I. van Vulpen¹⁰⁵, M. Vanadia⁹⁹,
 W. Vandelli²⁹, A. Vaniachine⁵, P. Vankov⁴¹, F. Vannucci⁷⁸, R. Vari^{132a}, T. Varol⁸⁴,
 D. Varouchas¹⁴, A. Vartapetian⁷, K.E. Varvell¹⁵⁰, V.I. Vassilakopoulos⁵⁶, F. Vazeille³³,
 T. Vazquez Schroeder⁵⁴, G. Vegni^{89a,89b}, J.J. Veillet¹¹⁵, F. Veloso^{124a}, R. Veness²⁹,
 S. Veneziano^{132a}, A. Ventura^{72a,72b}, D. Ventura⁸⁴, M. Venturi⁴⁸, N. Venturi¹⁵⁸,
 V. Vercesi^{119a}, M. Verducci¹³⁸, W. Verkerke¹⁰⁵, J.C. Vermeulen¹⁰⁵, A. Vest⁴³,
 M.C. Vetterli^{142,d}, I. Vichou¹⁶⁵, T. Vickey^{145b,ai}, O.E. Vickey Boeriu^{145b},
 G.H.A. Viehhauser¹¹⁸, S. Viel¹⁶⁸, M. Villa^{19a,19b}, M. Villaplana Perez¹⁶⁷, E. Vilucchi⁴⁷,
 M.G. Vincker²⁸, E. Vinek²⁹, V.B. Vinogradov⁶⁴, M. Virchaux^{136,*}, J. Virzi¹⁴,
 O. Vitells¹⁷², M. Viti⁴¹, I. Vivarelli⁴⁸, F. Vives Vaque², S. Vlachos⁹, D. Vladoiu⁹⁸,
 M. Vlasak¹²⁷, A. Vogel²⁰, P. Vokac¹²⁷, G. Volpi⁴⁷, M. Volpi⁸⁶, G. Volpini^{89a},
 H. von der Schmitt⁹⁹, J. von Loeben⁹⁹, H. von Radziewski⁴⁸, E. von Toerne²⁰,
 V. Vorobel¹²⁶, V. Vorwerk¹¹, M. Vos¹⁶⁷, R. Voss²⁹, T.T. Voss¹⁷⁵, J.H. Vossebeld⁷³,
 N. Vranjes¹³⁶, M. Vranjes Milosavljevic¹⁰⁵, V. Vrba¹²⁵, M. Vreeswijk¹⁰⁵, T. Vu Anh⁴⁸,
 R. Vuillermet²⁹, I. Vukotic¹¹⁵, W. Wagner¹⁷⁵, P. Wagner¹²⁰, H. Wahlen¹⁷⁵,
 S. Wahrmond⁴³, J. Wakabayashi¹⁰¹, S. Walch⁸⁷, J. Walder⁷¹, R. Walker⁹⁸,
 W. Walkowiak¹⁴¹, R. Wall¹⁷⁶, P. Waller⁷³, C. Wang⁴⁴, H. Wang¹⁷³, H. Wang^{32b,aj},
 J. Wang¹⁵¹, J. Wang⁵⁵, R. Wang¹⁰³, S.M. Wang¹⁵¹, T. Wang²⁰, A. Warburton⁸⁵,
 C.P. Ward²⁷, M. Warsinsky⁴⁸, A. Washbrook⁴⁵, C. Wasicki⁴¹, P.M. Watkins¹⁷,
 A.T. Watson¹⁷, I.J. Watson¹⁵⁰, M.F. Watson¹⁷, G. Watts¹³⁸, S. Watts⁸², A.T. Waugh¹⁵⁰,
 B.M. Waugh⁷⁷, M. Weber¹²⁹, M.S. Weber¹⁶, P. Weber⁵⁴, A.R. Weidberg¹¹⁸, P. Weigell⁹⁹,
 J. Weingarten⁵⁴, C. Weiser⁴⁸, H. Wellenstein²², P.S. Wells²⁹, T. Wenaus²⁴,
 D. Wendland¹⁵, Z. Weng^{151,w}, T. Wengler²⁹, S. Wenig²⁹, N. Wermes²⁰, M. Werner⁴⁸,

P. Werner²⁹, M. Werth¹⁶³, M. Wessels^{58a}, J. Wetter¹⁶¹, C. Weydert⁵⁵, K. Whalen²⁸, S.J. Wheeler-Ellis¹⁶³, A. White⁷, M.J. White⁸⁶, S. White^{122a,122b}, S.R. Whitehead¹¹⁸, D. Whiteson¹⁶³, D. Whittington⁶⁰, F. Wicek¹¹⁵, D. Wicke¹⁷⁵, F.J. Wickens¹²⁹, W. Wiedenmann¹⁷³, M. Wielers¹²⁹, P. Wienemann²⁰, C. Wigglesworth⁷⁵, L.A.M. Wiik-Fuchs⁴⁸, P.A. Wijeratne⁷⁷, A. Wildauer¹⁶⁷, M.A. Wildt^{41,s}, I. Wilhelm¹²⁶, H.G. Wilkens²⁹, J.Z. Will⁹⁸, E. Williams³⁴, H.H. Williams¹²⁰, W. Willis³⁴, S. Willocq⁸⁴, J.A. Wilson¹⁷, M.G. Wilson¹⁴³, A. Wilson⁸⁷, I. Wingerter-Seez⁴, S. Winkelmann⁴⁸, F. Winklmeier²⁹, M. Wittgen¹⁴³, S.J. Wollstadt⁸¹, M.W. Wolter³⁸, H. Wolters^{124a,h}, W.C. Wong⁴⁰, G. Wooden⁸⁷, B.K. Wosiek³⁸, J. Wotschack²⁹, M.J. Woudstra⁸², K.W. Wozniak³⁸, K. Wraight⁵³, C. Wright⁵³, M. Wright⁵³, B. Wrona⁷³, S.L. Wu¹⁷³, X. Wu⁴⁹, Y. Wu^{32b,ak}, E. Wulf³⁴, B.M. Wynne⁴⁵, S. Xella³⁵, M. Xiao¹³⁶, S. Xie⁴⁸, C. Xu^{32b,z}, D. Xu¹³⁹, B. Yabsley¹⁵⁰, S. Yacoob^{145b}, M. Yamada⁶⁵, H. Yamaguchi¹⁵⁵, A. Yamamoto⁶⁵, K. Yamamoto⁶³, S. Yamamoto¹⁵⁵, T. Yamamura¹⁵⁵, T. Yamanaka¹⁵⁵, J. Yamaoka⁴⁴, T. Yamazaki¹⁵⁵, Y. Yamazaki⁶⁶, Z. Yan²¹, H. Yang⁸⁷, U.K. Yang⁸², Y. Yang⁶⁰, Z. Yang^{146a,146b}, S. Yanush⁹¹, L. Yao^{32a}, Y. Yao¹⁴, Y. Yasu⁶⁵, G.V. Ybeles Smit¹³⁰, J. Ye³⁹, S. Ye²⁴, M. Yilmaz^{3c}, R. Yoosoofmiya¹²³, K. Yorita¹⁷¹, R. Yoshida⁵, C. Young¹⁴³, C.J. Young¹¹⁸, S. Youssef²¹, D. Yu²⁴, J. Yu⁷, J. Yu¹¹², L. Yuan⁶⁶, A. Yurkewicz¹⁰⁶, B. Zabinski³⁸, R. Zaidan⁶², A.M. Zaitsev¹²⁸, Z. Zajacova²⁹, L. Zanello^{132a,132b}, A. Zaytsev¹⁰⁷, C. Zeitnitz¹⁷⁵, M. Zeman¹²⁵, A. Zemla³⁸, C. Zendler²⁰, O. Zenin¹²⁸, T. Ženiš^{144a}, Z. Zinonos^{122a,122b}, S. Zenz¹⁴, D. Zerwas¹¹⁵, G. Zevi della Porta⁵⁷, Z. Zhan^{32d}, D. Zhang^{32b,aj}, H. Zhang⁸⁸, J. Zhang⁵, X. Zhang^{32d}, Z. Zhang¹¹⁵, L. Zhao¹⁰⁸, T. Zhao¹³⁸, Z. Zhao^{32b}, A. Zhemchugov⁶⁴, J. Zhong¹¹⁸, B. Zhou⁸⁷, N. Zhou¹⁶³, Y. Zhou¹⁵¹, C.G. Zhu^{32d}, H. Zhu⁴¹, J. Zhu⁸⁷, Y. Zhu^{32b}, X. Zhuang⁹⁸, V. Zhuravlov⁹⁹, D. Zieminska⁶⁰, N.I. Zimin⁶⁴, R. Zimmermann²⁰, S. Zimmermann²⁰, S. Zimmermann⁴⁸, M. Ziolkowski¹⁴¹, R. Zitoun⁴, L. Živković³⁴, V.V. Zmouchko^{128,*}, G. Zobernig¹⁷³, A. Zoccoli^{19a,19b}, M. zur Nedden¹⁵, V. Zutshi¹⁰⁶, L. Zwalinski²⁹.

¹ University at Albany, Albany NY, United States of America

² Department of Physics, University of Alberta, Edmonton AB, Canada

³ ^(a)Department of Physics, Ankara University, Ankara; ^(b)Department of Physics, Dumlupinar University, Kutahya; ^(c)Department of Physics, Gazi University, Ankara; ^(d)Division of Physics, TOBB University of Economics and Technology, Ankara; ^(e)Turkish Atomic Energy Authority, Ankara, Turkey

⁴ LAPP, CNRS/IN2P3 and Université de Savoie, Annecy-le-Vieux, France

⁵ High Energy Physics Division, Argonne National Laboratory, Argonne IL, United States of America

⁶ Department of Physics, University of Arizona, Tucson AZ, United States of America

⁷ Department of Physics, The University of Texas at Arlington, Arlington TX, United States of America

⁸ Physics Department, University of Athens, Athens, Greece

⁹ Physics Department, National Technical University of Athens, Zografou, Greece

¹⁰ Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan

- ¹¹ Institut de Física d'Altes Energies and Departament de Física de la Universitat Autònoma de Barcelona and ICREA, Barcelona, Spain
- ¹² ^(a)Institute of Physics, University of Belgrade, Belgrade; ^(b)Vinca Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia
- ¹³ Department for Physics and Technology, University of Bergen, Bergen, Norway
- ¹⁴ Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley CA, United States of America
- ¹⁵ Department of Physics, Humboldt University, Berlin, Germany
- ¹⁶ Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland
- ¹⁷ School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom
- ¹⁸ ^(a)Department of Physics, Bogazici University, Istanbul; ^(b)Division of Physics, Dogus University, Istanbul; ^(c)Department of Physics Engineering, Gaziantep University, Gaziantep; ^(d)Department of Physics, Istanbul Technical University, Istanbul, Turkey
- ¹⁹ ^(a)INFN Sezione di Bologna; ^(b)Dipartimento di Fisica, Università di Bologna, Bologna, Italy
- ²⁰ Physikalisches Institut, University of Bonn, Bonn, Germany
- ²¹ Department of Physics, Boston University, Boston MA, United States of America
- ²² Department of Physics, Brandeis University, Waltham MA, United States of America
- ²³ ^(a)Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro; ^(b)Federal University of Juiz de Fora (UFJF), Juiz de Fora; ^(c)Federal University of Sao Joao del Rei (UFSJ), Sao Joao del Rei; ^(d)Instituto de Fisica, Universidade de Sao Paulo, Sao Paulo, Brazil
- ²⁴ Physics Department, Brookhaven National Laboratory, Upton NY, United States of America
- ²⁵ ^(a)National Institute of Physics and Nuclear Engineering, Bucharest; ^(b)University Politehnica Bucharest, Bucharest; ^(c)West University in Timisoara, Timisoara, Romania
- ²⁶ Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina
- ²⁷ Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom
- ²⁸ Department of Physics, Carleton University, Ottawa ON, Canada
- ²⁹ CERN, Geneva, Switzerland
- ³⁰ Enrico Fermi Institute, University of Chicago, Chicago IL, United States of America
- ³¹ ^(a)Departamento de Física, Pontificia Universidad Católica de Chile, Santiago; ^(b)Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile
- ³² ^(a)Institute of High Energy Physics, Chinese Academy of Sciences, Beijing; ^(b)Department of Modern Physics, University of Science and Technology of China, Anhui; ^(c)Department of Physics, Nanjing University, Jiangsu; ^(d)School of Physics, Shandong University, Shandong, China
- ³³ Laboratoire de Physique Corpusculaire, Clermont Université and Université Blaise Pascal and CNRS/IN2P3, Aubiere Cedex, France
- ³⁴ Nevis Laboratory, Columbia University, Irvington NY, United States of America
- ³⁵ Niels Bohr Institute, University of Copenhagen, Kobenhavn, Denmark

- ³⁶ ^(a)INFN Gruppo Collegato di Cosenza; ^(b)Dipartimento di Fisica, Università della Calabria, Arcavata di Rende, Italy
- ³⁷ AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow, Poland
- ³⁸ The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland
- ³⁹ Physics Department, Southern Methodist University, Dallas TX, United States of America
- ⁴⁰ Physics Department, University of Texas at Dallas, Richardson TX, United States of America
- ⁴¹ DESY, Hamburg and Zeuthen, Germany
- ⁴² Institut für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany
- ⁴³ Institut für Kern- und Teilchenphysik, Technical University Dresden, Dresden, Germany
- ⁴⁴ Department of Physics, Duke University, Durham NC, United States of America
- ⁴⁵ SUPA - School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom
- ⁴⁶ Fachhochschule Wiener Neustadt, Johannes Gutenbergstrasse 32700 Wiener Neustadt, Austria
- ⁴⁷ INFN Laboratori Nazionali di Frascati, Frascati, Italy
- ⁴⁸ Fakultät für Mathematik und Physik, Albert-Ludwigs-Universität, Freiburg i.Br., Germany
- ⁴⁹ Section de Physique, Université de Genève, Geneva, Switzerland
- ⁵⁰ ^(a)INFN Sezione di Genova; ^(b)Dipartimento di Fisica, Università di Genova, Genova, Italy
- ⁵¹ ^(a)E.Andronikashvili Institute of Physics, Tbilisi State University, Tbilisi; ^(b)High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia
- ⁵² II Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany
- ⁵³ SUPA - School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom
- ⁵⁴ II Physikalisches Institut, Georg-August-Universität, Göttingen, Germany
- ⁵⁵ Laboratoire de Physique Subatomique et de Cosmologie, Université Joseph Fourier and CNRS/IN2P3 and Institut National Polytechnique de Grenoble, Grenoble, France
- ⁵⁶ Department of Physics, Hampton University, Hampton VA, United States of America
- ⁵⁷ Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA, United States of America
- ⁵⁸ ^(a)Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg; ^(b)Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg; ^(c)ZITI Institut für technische Informatik, Ruprecht-Karls-Universität Heidelberg, Mannheim, Germany
- ⁵⁹ Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan

- ⁶⁰ Department of Physics, Indiana University, Bloomington IN, United States of America
- ⁶¹ Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria
- ⁶² University of Iowa, Iowa City IA, United States of America
- ⁶³ Department of Physics and Astronomy, Iowa State University, Ames IA, United States of America
- ⁶⁴ Joint Institute for Nuclear Research, JINR Dubna, Dubna, Russia
- ⁶⁵ KEK, High Energy Accelerator Research Organization, Tsukuba, Japan
- ⁶⁶ Graduate School of Science, Kobe University, Kobe, Japan
- ⁶⁷ Faculty of Science, Kyoto University, Kyoto, Japan
- ⁶⁸ Kyoto University of Education, Kyoto, Japan
- ⁶⁹ Department of Physics, Kyushu University, Fukuoka, Japan
- ⁷⁰ Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina
- ⁷¹ Physics Department, Lancaster University, Lancaster, United Kingdom
- ⁷² ^(a)INFN Sezione di Lecce; ^(b)Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy
- ⁷³ Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom
- ⁷⁴ Department of Physics, Jožef Stefan Institute and University of Ljubljana, Ljubljana, Slovenia
- ⁷⁵ School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom
- ⁷⁶ Department of Physics, Royal Holloway University of London, Surrey, United Kingdom
- ⁷⁷ Department of Physics and Astronomy, University College London, London, United Kingdom
- ⁷⁸ Laboratoire de Physique Nucléaire et de Hautes Energies, UPMC and Université Paris-Diderot and CNRS/IN2P3, Paris, France
- ⁷⁹ Fysiska institutionen, Lunds universitet, Lund, Sweden
- ⁸⁰ Departamento de Física Teórica C-15, Universidad Autónoma de Madrid, Madrid, Spain
- ⁸¹ Institut für Physik, Universität Mainz, Mainz, Germany
- ⁸² School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom
- ⁸³ CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
- ⁸⁴ Department of Physics, University of Massachusetts, Amherst MA, United States of America
- ⁸⁵ Department of Physics, McGill University, Montreal QC, Canada
- ⁸⁶ School of Physics, University of Melbourne, Victoria, Australia
- ⁸⁷ Department of Physics, The University of Michigan, Ann Arbor MI, United States of America
- ⁸⁸ Department of Physics and Astronomy, Michigan State University, East Lansing MI, United States of America
- ⁸⁹ ^(a)INFN Sezione di Milano; ^(b)Dipartimento di Fisica, Università di Milano, Milano,

Italy

⁹⁰ B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Republic of Belarus

⁹¹ National Scientific and Educational Centre for Particle and High Energy Physics, Minsk, Republic of Belarus

⁹² Department of Physics, Massachusetts Institute of Technology, Cambridge MA, United States of America

⁹³ Group of Particle Physics, University of Montreal, Montreal QC, Canada

⁹⁴ P.N. Lebedev Institute of Physics, Academy of Sciences, Moscow, Russia

⁹⁵ Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia

⁹⁶ Moscow Engineering and Physics Institute (MEPhI), Moscow, Russia

⁹⁷ Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia

⁹⁸ Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany

⁹⁹ Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany

¹⁰⁰ Nagasaki Institute of Applied Science, Nagasaki, Japan

¹⁰¹ Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan

¹⁰² ^(a)INFN Sezione di Napoli; ^(b)Dipartimento di Scienze Fisiche, Università di Napoli, Napoli, Italy

¹⁰³ Department of Physics and Astronomy, University of New Mexico, Albuquerque NM, United States of America

¹⁰⁴ Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands

¹⁰⁵ Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands

¹⁰⁶ Department of Physics, Northern Illinois University, DeKalb IL, United States of America

¹⁰⁷ Budker Institute of Nuclear Physics, SB RAS, Novosibirsk, Russia

¹⁰⁸ Department of Physics, New York University, New York NY, United States of America

¹⁰⁹ Ohio State University, Columbus OH, United States of America

¹¹⁰ Faculty of Science, Okayama University, Okayama, Japan

¹¹¹ Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK, United States of America

¹¹² Department of Physics, Oklahoma State University, Stillwater OK, United States of America

¹¹³ Palacký University, RCPTM, Olomouc, Czech Republic

¹¹⁴ Center for High Energy Physics, University of Oregon, Eugene OR, United States of America

¹¹⁵ LAL, Université Paris-Sud and CNRS/IN2P3, Orsay, France

¹¹⁶ Graduate School of Science, Osaka University, Osaka, Japan

¹¹⁷ Department of Physics, University of Oslo, Oslo, Norway

¹¹⁸ Department of Physics, Oxford University, Oxford, United Kingdom

- ¹¹⁹ ^(a)INFN Sezione di Pavia; ^(b)Dipartimento di Fisica, Università di Pavia, Pavia, Italy
- ¹²⁰ Department of Physics, University of Pennsylvania, Philadelphia PA, United States of America
- ¹²¹ Petersburg Nuclear Physics Institute, Gatchina, Russia
- ¹²² ^(a)INFN Sezione di Pisa; ^(b)Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy
- ¹²³ Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA, United States of America
- ¹²⁴ ^(a)Laboratorio de Instrumentacao e Fisica Experimental de Particulas - LIP, Lisboa, Portugal; ^(b)Departamento de Fisica Teorica y del Cosmos and CAFPE, Universidad de Granada, Granada, Spain
- ¹²⁵ Institute of Physics, Academy of Sciences of the Czech Republic, Praha, Czech Republic
- ¹²⁶ Faculty of Mathematics and Physics, Charles University in Prague, Praha, Czech Republic
- ¹²⁷ Czech Technical University in Prague, Praha, Czech Republic
- ¹²⁸ State Research Center Institute for High Energy Physics, Protvino, Russia
- ¹²⁹ Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
- ¹³⁰ Physics Department, University of Regina, Regina SK, Canada
- ¹³¹ Ritsumeikan University, Kusatsu, Shiga, Japan
- ¹³² ^(a)INFN Sezione di Roma I; ^(b)Dipartimento di Fisica, Università La Sapienza, Roma, Italy
- ¹³³ ^(a)INFN Sezione di Roma Tor Vergata; ^(b)Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy
- ¹³⁴ ^(a)INFN Sezione di Roma Tre; ^(b)Dipartimento di Fisica, Università Roma Tre, Roma, Italy
- ¹³⁵ ^(a)Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies - Université Hassan II, Casablanca; ^(b)Centre National de l'Energie des Sciences Techniques Nucleaires, Rabat; ^(c)Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech; ^(d)Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda; ^(e)Faculté des sciences, Université Mohammed V-Agdal, Rabat, Morocco
- ¹³⁶ DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat a l'Energie Atomique), Gif-sur-Yvette, France
- ¹³⁷ Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA, United States of America
- ¹³⁸ Department of Physics, University of Washington, Seattle WA, United States of America
- ¹³⁹ Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
- ¹⁴⁰ Department of Physics, Shinshu University, Nagano, Japan
- ¹⁴¹ Fachbereich Physik, Universität Siegen, Siegen, Germany
- ¹⁴² Department of Physics, Simon Fraser University, Burnaby BC, Canada

- ¹⁴³ SLAC National Accelerator Laboratory, Stanford CA, United States of America
- ¹⁴⁴ ^(a)Faculty of Mathematics, Physics & Informatics, Comenius University, Bratislava;
^(b)Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic
- ¹⁴⁵ ^(a)Department of Physics, University of Johannesburg, Johannesburg; ^(b)School of Physics, University of the Witwatersrand, Johannesburg, South Africa
- ¹⁴⁶ ^(a)Department of Physics, Stockholm University; ^(b)The Oskar Klein Centre, Stockholm, Sweden
- ¹⁴⁷ Physics Department, Royal Institute of Technology, Stockholm, Sweden
- ¹⁴⁸ Departments of Physics & Astronomy and Chemistry, Stony Brook University, Stony Brook NY, United States of America
- ¹⁴⁹ Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom
- ¹⁵⁰ School of Physics, University of Sydney, Sydney, Australia
- ¹⁵¹ Institute of Physics, Academia Sinica, Taipei, Taiwan
- ¹⁵² Department of Physics, Technion: Israel Institute of Technology, Haifa, Israel
- ¹⁵³ Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
- ¹⁵⁴ Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
- ¹⁵⁵ International Center for Elementary Particle Physics and Department of Physics, The University of Tokyo, Tokyo, Japan
- ¹⁵⁶ Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan
- ¹⁵⁷ Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
- ¹⁵⁸ Department of Physics, University of Toronto, Toronto ON, Canada
- ¹⁵⁹ ^(a)TRIUMF, Vancouver BC; ^(b)Department of Physics and Astronomy, York University, Toronto ON, Canada
- ¹⁶⁰ Institute of Pure and Applied Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8571, Japan
- ¹⁶¹ Science and Technology Center, Tufts University, Medford MA, United States of America
- ¹⁶² Centro de Investigaciones, Universidad Antonio Narino, Bogota, Colombia
- ¹⁶³ Department of Physics and Astronomy, University of California Irvine, Irvine CA, United States of America
- ¹⁶⁴ ^(a)INFN Gruppo Collegato di Udine; ^(b)ICTP, Trieste; ^(c)Dipartimento di Chimica, Fisica e Ambiente, Università di Udine, Udine, Italy
- ¹⁶⁵ Department of Physics, University of Illinois, Urbana IL, United States of America
- ¹⁶⁶ Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden
- ¹⁶⁷ Instituto de Física Corpuscular (IFIC) and Departamento de Física Atómica, Molecular y Nuclear and Departamento de Ingeniería Electrónica and Instituto de Microelectrónica de Barcelona (IMB-CNM), University of Valencia and CSIC, Valencia, Spain
- ¹⁶⁸ Department of Physics, University of British Columbia, Vancouver BC, Canada

- ¹⁶⁹ Department of Physics and Astronomy, University of Victoria, Victoria BC, Canada
- ¹⁷⁰ Department of Physics, University of Warwick, Coventry, United Kingdom
- ¹⁷¹ Waseda University, Tokyo, Japan
- ¹⁷² Department of Particle Physics, The Weizmann Institute of Science, Rehovot, Israel
- ¹⁷³ Department of Physics, University of Wisconsin, Madison WI, United States of America
- ¹⁷⁴ Fakultät für Physik und Astronomie, Julius-Maximilians-Universität, Würzburg, Germany
- ¹⁷⁵ Fachbereich C Physik, Bergische Universität Wuppertal, Wuppertal, Germany
- ¹⁷⁶ Department of Physics, Yale University, New Haven CT, United States of America
- ¹⁷⁷ Yerevan Physics Institute, Yerevan, Armenia
- ¹⁷⁸ Domaine scientifique de la Doua, Centre de Calcul CNRS/IN2P3, Villeurbanne Cedex, France
- ^a Also at Laboratório de Instrumentação e Física Experimental de Partículas - LIP, Lisboa, Portugal
- ^b Also at Faculdade de Ciências and CFNUL, Universidade de Lisboa, Lisboa, Portugal
- ^c Also at Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
- ^d Also at TRIUMF, Vancouver BC, Canada
- ^e Also at Department of Physics, California State University, Fresno CA, United States of America
- ^f Also at Novosibirsk State University, Novosibirsk, Russia
- ^g Also at Fermilab, Batavia IL, United States of America
- ^h Also at Department of Physics, University of Coimbra, Coimbra, Portugal
- ⁱ Also at Department of Physics, UASLP, San Luis Potosi, Mexico
- ^j Also at Università di Napoli Parthenope, Napoli, Italy
- ^k Also at Institute of Particle Physics (IPP), Canada
- ^l Also at Department of Physics, Middle East Technical University, Ankara, Turkey
- ^m Also at Louisiana Tech University, Ruston LA, United States of America
- ⁿ Also at Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal
- ^o Also at Department of Physics and Astronomy, University College London, London, United Kingdom
- ^p Also at Group of Particle Physics, University of Montreal, Montreal QC, Canada
- ^q Also at Department of Physics, University of Cape Town, Cape Town, South Africa
- ^r Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan
- ^s Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany
- ^t Also at Manhattan College, New York NY, United States of America
- ^u Also at School of Physics, Shandong University, Shandong, China
- ^v Also at CPPM, Aix-Marseille Université and CNRS/IN2P3, Marseille, France
- ^w Also at School of Physics and Engineering, Sun Yat-sen University, Guanzhou, China
- ^x Also at Academia Sinica Grid Computing, Institute of Physics, Academia Sinica, Taipei, Taiwan

- ^y Also at Dipartimento di Fisica, Università La Sapienza, Roma, Italy
- ^z Also at DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), CEA Saclay (Commissariat à l'Energie Atomique), Gif-sur-Yvette, France
- ^{aa} Also at Section de Physique, Université de Genève, Geneva, Switzerland
- ^{ab} Also at Departamento de Fisica, Universidade de Minho, Braga, Portugal
- ^{ac} Also at Department of Physics and Astronomy, University of South Carolina, Columbia SC, United States of America
- ^{ad} Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary
- ^{ae} Also at California Institute of Technology, Pasadena CA, United States of America
- ^{af} Also at Institute of Physics, Jagiellonian University, Krakow, Poland
- ^{ag} Also at LAL, Université Paris-Sud and CNRS/IN2P3, Orsay, France
- ^{ah} Also at Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
- ^{ai} Also at Department of Physics, Oxford University, Oxford, United Kingdom
- ^{aj} Also at Institute of Physics, Academia Sinica, Taipei, Taiwan
- ^{ak} Also at Department of Physics, The University of Michigan, Ann Arbor MI, United States of America
- * Deceased